ROCK SOLE

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EXECUTIVE SUMMARY

The following changes have been made to this assessment relative to the November 2002 SAFE:

Changes to the input data

1) 2002 fishery age composition.
2) 2002 survey age composition.
3) 2003 trawl survey biomass point estimate and standard error.
4) Estimate of catch (t) and discards through 27, September 2003.
5) Estimate of retained and discarded portions of the 2001 and 2002 catch.

Assessment results

1) The projected age 2+ biomass for 2004 is 1,164,000 t.
2) The projected female spawning biomass for 2004 is 424,600 t.
3) The recommended 2004 ABC is 139,300 t based on an $F_{40\%}$ (0.173) harvest level.
4) The 2004 overfishing level is 166,300 t based on an $F_{35\%}$ (0.21) harvest level.

New Analysis

Survey catchability is estimated with a prior estimate on catchability from results of a herding experiment.

SUMMARY

	2003 Assessment Recommendations for the 2004 harvest	2002 Assessment Recommendations for the 2003 harvest
Total biomass	1,164,000 t	877,200 t
ABC	139,300 t	110,200 t
Overfishing	166,300 t	131,700 t
F_{ABC}	$F_{0.40} = 0.173$	$F_{0.40} = 0.176$
$F_{overfishing}$	$F_{0.35} = 0.21$	$F_{0.35} = 0.213$

INTRODUCTION

Northern rock sole (Lepidopsetta polyxystra n. sp.) are distributed primarily on the eastern Bering Sea continental shelf and in much lesser amounts in the Aleutian Islands region. Two species of rock sole are known to occur in the North Pacific ocean, a northern rock sole (L. polyxystra) and a southern rock sole (L. bilineata) (Orr and Matarese 2000). These species have an overlapping distribution in the Gulf of Alaska, but the northern species predominates the Bering Sea and Aleutian Islands populations where they are managed as a single stock.

Centers of abundance occur off the Kamchatka Peninsula (Shubnikov and Lisovenko 1964), British Columbia (Forrester and Thompson 1969), the central Gulf of Alaska, and in the southeastern Bering Sea (Alton and Sample 1975). Adults exhibit a benthic lifestyle and, in the eastern Bering Sea, occupy separate winter (spawning) and summertime feeding distributions on the continental shelf. Northern rock sole spawn during the winter-early spring period of December-March.

CATCH HISTORY

Rock sole catches increased from an average of 7,000 t annually from 1963-69 to 30,000 t between 1970 to 1975. Catches (t) since implementation of the MFCMA in 1977 are shown in Table 7.1, with catch data for 1980-88 separated into catches by non-U.S. fisheries; joint venture operations and DAP catches (where available). Prior to 1987, the classification of rock sole in the "other flatfish" management category prevented reliable estimates of DAP catch. Catches from 1989 - 2001 (DAP only) have averaged 50,700 t annually. The size composition of the 2002 catch from observer sampling, by sex and management area, are shown in Figure 7.1 and the catch locations in 2001, by quarter, are shown in the Appendix.

Rock sole are important as the target of a high value roe fishery occurring in February and March which accounts for the majority of the annual catch. The 2002 catch of 41,311 t was only 18% of the ABC of 225,000 t (77% of the TAC). The 2003 catch total is 35,100 t through September 27. Thus, rock sole remain lightly harvested in the Bering Sea and Aleutian Islands.

During the 2003 fishing season rock sole harvesting was periodically closed in the Bering Sea and Aleutian Islands due to bycatch restrictions, as follows:

Area	Date	Bycatch closure
Zone 1	2/14 – 12/31	Annual red king crab cap
BS/AI	2/18 - 4/1	Exceed interim halibut cap
BS/AI	4/1 - 7/1	Second seasonal halibut cap
BS/AI	7/31 - 12/31	Annual halibut allowance

Although female rock sole are highly desirable when in spawning condition, large amounts of rock sole are discarded overboard in the various Bering Sea trawl target fisheries. Observer discard estimates applied to 'blend' estimates of observer sampling and industry reported catch provide the following estimates:

Year	Retained	Discard	% Retained
1987	14,209 t	14,701 t	49
1988	22,374 t	23,148 t	49
1989	23,544 t	24,358 t	49
1990	12,170 t	12,591 t	49
1991	25,406 t	35,181 t	42
1992	21,317 t	35,681 t	37
1993	22,589 t	45,669 t	33
1994	20,951 t	39,945 t	34
1995	21,761 t	33,108 t	40
1996	19,770 t	27,158 t	42
1997	27,743 t	39,821 t	41
1998	12,645 t	20,999 t	38
1999	15,224 t	25,286 t	38
2000	22,151 t	27,113 t	45
2001	19,299 t	9,956 t	66
2002	23,607 t	17,724 t	57

From 1987 to 2000 rock sole were discarded in greater amounts than they were retained. The past two years indicate increased utilization of the catch. Fisheries with the highest discard rates include the rock sole roe fishery, the yellowfin sole, flathead sole, Pacific cod, and the bottom pollock fisheries (Table 7.2).

DATA

The data used in this assessment include estimates of total catch, trawl fishery catch-at-age, trawl survey age composition, trawl survey biomass estimates and sampling error, maturity observations from observer sampling and mean weight-at-age.

Fishery Catch and Catch-at-Age

Available information include fishery total catch data from 1975-September 27, 2003 (Table 7.1) and fishery catch-at-age numbers from 1980-2002 (Table 7.3).

Survey CPUE

Since rock sole are lightly exploited and are often taken incidentally in target fisheries for other species, CPUE from commercial fisheries are considered an unreliable method for detecting trends in abundance. It is therefore necessary to use research vessel survey data to assess the condition of these stocks.

Abundance estimates from the 1982 AFSC survey were substantially higher than from the 1981 survey data for a number of bottom-tending species such as flatfishes. This is coincident with the change in research trawl to the 83/112 with better bottom tending characteristics. The increase in survey CPUE was particularly large for rock sole (6.5 to 12.3 kg/ha, Figure 7.2). Consequently, CPUE and biomass from the 1975-81 surveys are not used in the assessment model.

The CPUE trend indicates a significantly increasing population from 1982-92 when the mean CPUE more than tripled. The population leveled-off from 1994-98 when CPUE values indicated a high level of abundance. The 1999 value of 36.5 kg/ha was the lowest observed since 1992, possibly due to extremely low water temperatures. Since that time the value seems to be stabilizing and reached 46.1 in 2003.

<u>Absolute Abundance</u>

Estimates of rock sole biomass are also estimated from the AFSC surveys using stratified area-swept expansion of the CPUE data. The estimates are as follows:

Year	Eastern Bering Sea (t)	Aleutian Islands (t)
1975	175,500	
1979	194,700	
1980	283,800	28,500
1981	302,400	
1982	578,800	
1983	713,000	23,300
1984	799,300	
1985	700,100	
1986	1,031,400	26,900
1987	1,269,700	
1988	1,480,100	
1989	1,138,600	
1990	1,381,300	
1991	1,588,300	37,325
1992	1,543,900	
1993	2,123,500	
1994	2,894,200	54,785
1995	2,175,040	
1996	2,183,000	
1997	2,710,900	56,154
1998	2,168,700	
1999	1,689,100	
2000	2,127,700	45,949
2001	2,415,000	
2002	1,901,800	57,700
2003	2,135,000	

It should be recognized that the biomass estimates given above are point estimates from an "area-swept" bottom trawl survey. As a result they are uncertain. It is assumed that the sampling plan covers the distribution of the fish and that all fish in the path of the footrope of the trawl are captured. That is, there are no losses due to escape or gains due to gear herding effects. Due to sampling variability alone, the 95% confidence interval for the 2003 point estimate of the Bering Sea surveyed area is 1,739,983 t - 2,530,883 t.

Rock sole biomass was relatively stable through 1979, but then increased substantially in the following years to 799,300 t in 1984. In 1985 the estimate declined to 672,000 t but increased again in 1986 to over 1 million t and continued this trend through 1988. The 1989 and 1990 estimates were at a high and stable level (slightly less than the 1988 estimate) and continued to increase to the highest level estimated by the trawl survey at 2.9 million metric tons in 1994. The 1995, 1996 and 1998 estimates are near the 1993 estimate of 2.2 million metric tons and the 1997 estimate is about the level of 1994.

Sharp increases in trawl survey abundance estimates for most species of Bering Sea flatfish between 1981 and 1982 indicate that the 83-112 trawl was more efficient for capturing these species than the 400-mesh eastern trawl used in 1975, and 1979-81. Allowing the stock assessment model to tune to these early survey estimates would most likely underestimate the true pre-1982 biomass, thus exaggerating the degree to which biomass increased during that period. The pre-1982 survey biomass estimates were omitted from the analysis.

Weight-at-age and Maturity-at-age

In conjunction with the large and steady increase in the rock sole stock size since the early 1980s, it was found that there was also a corresponding decrease in size-at-age for both sexes (Figure 7.3). This also caused a resultant decrease in weight-at-age as the population increased and expanded westward toward the shelf edge (Walters and Wilderbuer 2000). These updated values of weight-at-age (Table 7.4) were used in this assessment to model the population dynamics of the rock sole population.

The length-weight relationship did not change significantly over this time period as discerned from an analysis of observations made in 1975, 1976 and 1988. The following parameters have been calculated for the length (cm)-weight (g) relationship:

$$W = a * L ^{** b}$$

No significant differences were found between sexes so that these parameters are for both sexes combined.

a	b
0.007610	3.11976

Maturity information available from anatomical scans collected by fishery observers during the 1993 and 1994 Bering Sea rock sole roe fishery are used in this assessment (Table 7.5). These data indicate that the age of 50% maturity occurs at 9-10 years for female rock sole.

Survey and Fishery Age composition

Rock sole otoliths have routinely been collected during the trawl surveys since 1975 to provide estimates of the population age composition (Fig. 7.4, Table 7.6). Fishery size composition data from 1980-97 (prior to 1980 observer coverage was sparse and did not reflect the catch size composition) were applied to age-length keys from these surveys to provide a time-series of catch-at-age assuming that the mean length at age from the trawl survey was the same as the fishery in a given year. Estimation of the fishery age composition since 1997 used age-length keys derived from age structures collected annually from the fishery.

ANALYTIC APPROACH

Model Structure

The abundance, mortality, recruitment and selectivity of rock sole were assessed with a stock assessment model using the AD Model builder software. The conceptual model is similar to that implemented in the stock synthesis program (Methot 1990, Fournier and Archibald 1982). The model is a separable catch-age analysis that uses survey estimates of biomass and age composition as auxiliary information. The model simulates the dynamics of the population and compares the expected values of the population characteristics to the characteristics observed from surveys and fishery sampling programs. This is accomplished by the simultaneous estimation of the parameters in the model using the maximum likelihood estimation procedure. The fit of the simulated values to the observable characteristics is optimized by maximizing a log(likelihood) function.

The suite of parameters estimated by the model are classified by three likelihood components:

Data Component	Distribution assumption
Trawl fishery catch-at-age	Multinomial
Trawl survey population age composition	Multinomial
Trawl survey biomass estimates and S.E.	Log normal

The total log likelihood is the sum of the likelihoods for each data component (Table 7-7). The likelihood components may be weighted by an emphasis factor, however, equal emphasis was placed on fitting each likelihood component in the rock sole assessment except for the catch weight. The AD Model Builder software fits the data components using automatic differentiation (Griewank and Corliss 1991) software developed as a set of libraries (AUTODIFF C++ library). Table 7-7 presents the key equations used to model the rock sole population dynamics in the Bering Sea and Table 7-8 provides a description of the variables used in Table 7-7. The model of rock sole population dynamics was evaluated with respect to the observations of the time-series of survey and fishery age compositions and the survey biomass trend since 1982.

Parameters Estimated Independently

Most studies assume M = 0.20 for rock sole on the basis of the longevity of the species. In a past assessment, the stock synthesis model was used to entertain a range of M values to evaluate the fit of the observable population characteristics over a range of natural mortality values (Wilderbuer and Walters 1992). The best fit occurred at M = 0.18, which is the value used in this assessment. Past assessments have also set the survey catchability coefficient (q) equal to 1.0.

Rock sole maturity schedules were estimated as discussed in a previous section (Table 7.5).

Parameters Estimated Conditionally

The parameters estimated by the model are presented below:

Fishing mortality	Selectivity	Year class strength	Spawner-recruit	Total
29	4	48	2	83

The increase in the number of parameters estimated in this assessment compared to last year can be accounted for by the input of another year of fishery data and the entry of another year class into the

observed population.

Year class strengths

The population simulation specifies the numbers-at-age in the beginning year of the simulation, the number of recruits in each subsequent year, and the survival rate for each cohort as it moves through the population using the population dynamics equations given in Table 7-7.

Selectivity

Fishery and survey selectivity were modeled in this assessment using the logistic function, as shown in Table 7-7. The model was configured with the selectivity curve constrained to provide an asymptotic fit for the older fish in the fishery and survey, but still was allowed to estimate the shape of the logistic curve for young fish. The oldest year classes in the surveys and fisheries were truncated at 20 and allowed to accumulate into the age category 20+ years.

Fishing Mortality

The fishing mortality rates (F) for each age and year are calculated to approximate the catch weight by solving for F while still allowing for observation error in catch measurement. A large emphasis (300) was placed on the catch likelihood component.

Survey Catchability

Unusually low estimates of flatfish biomass were obtained for Bering Sea shelf flatfish species during the very cold year of 1999. These results suggest a relationship between bottom water temperature and trawl survey catchabililty, which was documented for yellowfin sole in the 2001 BSAI SAFE document. To better understand how water temperature may affect the catchability of rock sole to the survey trawl, we estimated catchability in a linear model for each year within the stock assessment model as:

$$q = \alpha + \beta T$$

where q is catchability, T is the average annual bottom water temperature at survey stations less than 100 m, and α and β are parameters estimated by the model. The model estimated values of α and β at 1.77 and 0.021, respectively. The small value for β indicates that temperature has very little effect on trawl catchability of rock sole and the value of 1.77 obtained for α suggests that survey catchability (q) is greater than 1.0, the value used in past assessments.

Experiments conducted in recent years on the standard research trawl used in the annual trawl surveys indicate that rock sole are herded by the bridles (in contact with the seafloor) from the area outside the net mouth into the trawl path (Somerton and Munro 2001). Rock sole survey trawl catchability was estimated at 1.4 from these experiments which indicate that the standard area-swept biomass estimate from the survey is an overestimate of the rock sole population biomass.

These experimental results, in combination with the results of the bottom temperature analysis above, provided a compelling reason to consider an alternative model where survey catchability is estimated. In the 2002 assessment (Wilderbuer and Walters 2002), model runs were made to profile the total log(likelihood) over a range of q values from 1.0 to 2.2 (M was fixed at 0.18 and selectivity was estimated) to find which value of q gave the best overall fit to the observed data values. Results from these model runs indicated that the best model fit to the observable information occurred when q = 1.82. The model fit best at this value primarily due to the improvement in matching the observed survey age composition data, primarily in the last 5 years. This revised estimated of q resulted in a large decrease in the estimate of total biomass relative to the previous assessment where q was fixed at 1.0.

In this assessment we used the value of q from the herding experiment as a prior on survey catchabliity and then estimated survey catchabililty as follows:

$$q_{mod} = 0.5\left[\frac{q_{exp} - q_{mod}}{\sigma_{exp}}\right]^2$$

where q_{model} is the survey catchability parameter estimated by the model, q_{exp} is the estimate of area-swept q from the herding experiment, and σ is the standard error of the experimental estimate of q.

Model Evaluation

Configuring the model by constraining the estimates of q with an experimental value as described above gives the best fit to the total likelihood with q = 1.45. The profile likelihood of survey catchability for rock sole given the observed data is shown in Figure 7.5. The likely values of q are tightly distributed around the maximum of 1.45 with narrow 95% confidence intervals that range from 1.34 to 1.57. The probability of q being 1.0 (as used in the 2001 assessment) appears to be very low. This result is consistent with the hypothesis that q > 1.0 as indicated from experimental results to determine the herding characteristics of the research trawl

Fixing the value of q at 1.8, as in last years assessment, gives the following comparison to the data likelihood components.

	q = 1.8	**q = 1.45**
survey biomass	49.2	48.6
Catch	0.0	0.0
fishery age composition	618.0	615.6
survey age composition	333.3	338.3
recruitment	66.5	67.1
total likelihood due to data	1067.0	1069.6

The new model run (q = 1.45) provided comparable fits to all data components. Survey biomass and fishery age composition were fit better and survey age composition and recruitment not as well. The new model run results in an increase to the estimates of total and female spawning biomass relative to the 2002 assessment. The value of q obtained in this assessment is preferred to the value (1.82) obtained for q in the 2002 assessment since it takes into consideration the prior value.

MODEL RESULTS

Fishing Mortality and Selectivity

The assessment model estimates of the annual fishing mortality on fully selected ages and the estimated annual exploitation rates (catch/total biomass) are given Table 7.9. The exploitation rate has averaged 3% from 1975-2003, indicating a lightly exploited stock. Age-specific selectivity estimated by the model (Table 7.10, Fig. 7.6) indicate that rock sole are 50% selected by the fishery between the ages of 8 and 9 and are fully selected by age 12 (sexes combined).

Abundance Trend

The stock assessment model indicates that rock sole total biomass was at low levels during the mid 1970s through 1982 (200,000 - 500,000 t, Fig. 7.6 and Table 7.11). From 1982-95, a period characterized by sustained above-average recruitment (1980-88 year classes, Fig. 7.6) and light exploitation, the estimated total biomass rapidly increased at a high rate to nearly 2.0 million t by 1995. Since then, the model indicates the population biomass has declined 38% to 1.23 million t in 2003 and is projected at 1.164 million t for 2004. This decline is attributable to the below-average recruitment to the adult portion of the population during the 1990s. The female spawning biomass is estimated to be at a high, but slowly declining level of 432,500 t in 2003 (Table 7.11). The model provides good fits to most of the strong year classes observed in the fishery and surveys during the time-series. These are shown in the Appendix with the model estimates of population numbers at age.

The model estimates of survey biomass (using trawl survey age-specific selectivity and the estimate of q from Model B applied to the total biomass, Fig. 7.6) corresponded fairly well with the trawl survey biomass trend through 1998. The 1999 survey point estimate is 200,000 t less than the model estimate whereas the past three survey biomass estimates have ranged from 300,000 t to 600,000 t higher than the model estimate of survey biomass. Both the trawl survey and the model indicate the same increasing biomass trend from the late 1970s to the mid 1990s but the survey does not indicate the declining trend from modeling results. The large variability in the survey biomass estimates during the last 5 years is not consistent with the observed age composition during this period and is not fit well by the model.

Total Biomass

The stock assessment model estimates of total biomass (begin year population numbers multiplied by mid-year weight at age) is used to recommend the ABC for 2004. Including the 2003 catch of 35,150 t through 27 September (including discards), the model projects the total biomass for 2004 at **1,164,000** t.

Recruitment Trends

Increases in abundance described earlier for rock sole can be attributed to the recruitment of a series of strong year classes (Figs. 7.4 and 7.6, Table 7.11). Rock sole ages have now been read for samples obtained in 2002 and show the continuing presence of the 1987 year class (Fig. 7.6). The 1990 year class, as 12 year old fish in 2002, comprise a significant part of the survey and fishery age composition numbers. The 1987 year class is the largest estimated during the recruitment time-series and still comprise 12% of the estimated 2002 survey age composition numbers as fifteen year old fish. Recruitment after 1990 has been below the 26 year average.

Tier 1 Considerations

The SSC has requested that flatfish assessments which have a lengthy time-series of stock and recruitment estimates explore management under a Tier 1 harvest policy. In the case of rock sole, the time series of recruitment estimates from this assessment is 28 years. MSY is an equilibrium concept and it's calculated value is dependent on both the spawner-recruit data, which we assume represents the equilibrium stock size-recruitment relationship, and the model used to fit the data. In the stock assessment model used here, a Ricker form of the stock-recruit relationship was fit to these data and estimates of F_{MSY} and B_{MSY} (female spawning biomass) were calculated, assuming that the fit to the stock-recruitment data points represent the long-term productivity of the stock. However, very different estimates of F_{MSY} and B_{MSY} were obtained, depending on which years of stock-recruitment data points were included in the fitting procedure. Fitting the full time series since the regime shift in 1977 (1978-99) gives values of **F_{MSY}=0.53, B_{MSY}=87,510 t, and MSY = 101,230 t**.

A recent analysis of flatfish recruitment give compelling evidence that temporal trends in winter spawning flatfish production in the Eastern Bering Sea are consistent with the hypothesis that decadal scale climate variability influences marine survival during the early life history period (Wilderbuer et al. 2002). Periods of estimated cross-shelf advection of flatfish larvae was found to coincide with synchronous above-average recruitment (1980s) whereas periods of weak advection or advection to the west were associated with poor recruitment (1990s) (Fig 7.7). These changes in stock productivity were found to coincide with a decadal scale shift in atmospheric forcing. When the spawner-recruit information from the1978-89 (productive) period were fit, estimates were obtained as follows: **F_{MSY}=0.28, B_{MSY}=3.72 E+12 t, and MSY = 5.85 E+12 t**. These estimates are clearly unrealistic and unreliable and only result from 12 observations (estimates).

This exercise of fitting spawner-recruit observations calls into concern whether a single fit of stock recruitment time-series data is able to reliably capture the long-term reproductive potential of the rock sole stock, particularly given the length of the time-series and the stock dynamics which have occurred since 1975. The aforementioned analysis was performed for rock sole, arrowtooth flounder and flathead sole, species which spawn in the winter in offshore areas and are seemingly reliant upon advection to nursery areas 3-4 months later. The atmospheric forcing responsible for the advection properties during this time period appears to be the location of the springtime signature of the Aleutian Low Pressure field. Anomalous sea level pressure implies that westerly to south-westerly surface winds (on-shelf) predominated during 1977-1988, whereas during 1989-96 easterly (off-shelf) winds were predominate. These shifts in recruitment production may be a cause of concern if we assume that the long term productivity is closely related to only spawning stock size while ignoring mechanisms governing the variability in production which may correspond to decadal (or longer) shifts in environmental conditions.

Given these concerns, the authors plan to perform a simulation study to determine the appropriateness of applying a harvest strategy from fitting the full time series for a fish stock experiencing temporal changes in reproductive potential due to changing oceanic conditions. For this assessment then, we recommend a continued Tier 3 harvest strategy.

ACCEPTABLE BIOLOGICAL CATCH

The reference fishing mortality rate for rock sole is determined by the amount of reliable population information available (Amendment 56 of the Fishery Management Plan for the groundfish fishery of the Bering Sea/Aleutian Islands). Equilibrium female spawning biomass is calculated by applying the female spawning biomass per recruit resulting from a constant $F_{0.40}$ harvest to an estimate of average equilibrium recruitment. For this assessment, year classes spawned in 1977 through 2002 are used to calculate the average equilibrium recruitment. This results in an estimate of **$B_{0.40}$ = 203,000 t**. The stock assessment model estimates the 2004 level of female spawning biomass at **424,600 t** (B). Since reliable estimates of B, $B_{0.40}$, $F_{0.40}$, and $F_{0.30}$ exist and $B > B_{0.40}$ (424,600 > 203,000, fig. 7.7), rock sole reference fishing mortality is defined in tier 3a. For the 2004 harvest: $F_{ABC} \leq F_{0.40} = 0.173$ and $F_{overfishing} = F_{0.35} = 0.21$ (full selection F values).

Acceptable biological catch is estimated for 2004 by applying the $F_{0.40}$ fishing mortality rate and age-specific fishery selectivities to the 2004 estimate of age-specific total biomass as follows:

$$ABC = \sum_{a=a_r}^{a_{nages}} \overline{w}_a n_a \left(1 - e^{-M-Fs_a}\right) \frac{Fs_a}{M + Fs_a}$$

where S_a is the selectivity at age, M is natural mortality, W_a is the mean weight at age from 2000, and n_a is the beginning of the year numbers at age. This results in a **2004 ABC of 139,300** t for the eastern Bering Sea portion of the stock.

The stock assessment analysis must also consider harvest limits, usually described as “overfishing” fishing mortality levels with corresponding yield amounts. Amendment 56 to the BS/AI FMP now sets the harvest limit at the $F_{0.35}$ fishing mortality value. The overfishing fishing mortality value, ABC fishing mortality value and their corresponding yields are given as follows:

Harvest level	F value	2004 Yield
$F_{0.35}$	0.210	166,300 t
$F_{0.40}$	0.176	139,300 t

BIOMASS PROJECTIONS

As in past years, a standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2003 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2004 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2003. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2004, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2004 recommended in the assessment to the *max* F_{ABC} for 2003. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)

Scenario 3: In all future years, F is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 4: In all future years, F is set equal to the 1999-2003 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follow (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above ½ of its MSY level in 2004 and above its MSY level in 2014 under this scenario, then the stock is not overfished.)

Scenario 7: In 2004 and 2005, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2016 under this scenario, then the stock is not approaching an overfished condition.)

Simulation results shown in Table 7.13 indicate that rock sole are currently not overfished and are not approaching an overfished condition. If harvested at the average F from 1999-2003, rock sole female spawning biomass is projected to decline over the next five years due to the reduced recruitment observed during the 1990s (fig. 7.9).

ECOSYSTEM CONSIDERATIONS

Ecosystem Effects on the stock

1) Prey availability/abundance trends

Rock sole diet by life stage varies as follows: Larvae consume plankton and algae, early juveniles consume zooplankton, late juvenile stage and adults prey includes bivalves, polychaetes, amphipods, mollusks and miscellaneous crustaceans. Information is not available to assess the abundance trends of the benthic infauna of the Bering Sea shelf. The original description of infaunal distribution and abundance by Haflinger (1981) resulted from sampling conducted in 1975 and 1976 and has not be re-sampled since. The large populations of flatfish which have occupied the middle shelf of the Bering Sea over the past twenty years for summertime feeding do not appear food-limited. These populations have fluctuated due to the variability in recruitment success which suggests that the primary infaunal food source has been at an adequate level to sustain the rock sole resource.

2) Predator population trends

As juveniles, it is well-documented from studies in other parts of the world that flatfish are prey for shrimp species in near shore areas. This has not been reported for Bering Sea rock sole due to a lack of juvenile sampling and collections in near shore areas, but is thought to occur. As late juveniles they are found in stomachs of pollock, Pacific cod, yellowfin sole, skates and Pacific halibut; mostly on small rock sole ranging from 5 to 15 cm standard length..

Past, present and projected future population trends of these predator species can be found in their respective SAFE chapters in this volume. Encounters between rock sole and their predators may be limited as their distributions do not completely overlap in space and time.

3) Changes in habitat quality

Changes in the physical environment which may affect rock sole distribution patterns, recruitment success, migration timing and patterns are catalogued in the Ecosystem Considerations Appendix of this SAFE report. Habitat quality may be enhanced during years of favorable cross-shelf advection (juvenile survival) and warmer bottom water temperatures with reduced ice cover (higher metabolism with more active feeding).

Fishery Effects on the ecosystem

1) The rock sole target fishery contribution to the total bycatch of other non-prohibited species is shown for 1991-2002 in Table 7.14. The rock sole target fishery contribution to the total bycatch of prohibited species is shown for 2001 and 2002 in Table 14 of the Economic SAFE (Appendix C) and is summarized for 2002 as follows:

Prohibited species	Rock sole fishery % of total bycatch
Halibut mortality	21.5
Herring	1.8
Red King crab	51.0
C. bairdi	31.8
Other Tanner crab	9.2
Salmon	< 1

2) Relative to the predator needs in space and time, the rock sole target fishery is not very selective for fish between 5-15 cm and therefore has minimal overlap with removals from predation.

3) The target fishery is not perceived to have an effect on the amount of large size target fish in the population due to it's history of very light exploitation (3%) over the past 28 years.

4) Rock sole fishery discards are presented in the Catch History section.

5) It is unknown what effect the fishery has had on rock sole maturity-at-age and fecundity.

6) Analysis of the benthic disturbance from the rock sole fishery is available in the Preliminary draft of the Essential Fish Habitat environmental Impact Statement.

Ecosystem effects on rock sole			
Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Benthic infauna	Stomach contents	Stable, data limited	Unknown
Predator population trends			
Fish (Pollock, Pacific cod, halibut, yellowfin sole, skates)	Stable	Possible increases to rock sole mortality	
Changes in habitat quality			
Temperature regime	Cold years rock sole catchability and herding may decrease	Likely to affect surveyed stock	No concern (dealt with in model)
Winter-spring environmental conditions	Affects pre-recruit survival	Probably a number of factors	Causes natural variability

***Rock sole* effects on ecosystem**			
Indicator	Observation	Interpretation	Evaluation
Fishery contribution to bycatch			
Prohibited species	Stable, heavily monitored	Minor contribution to mortality	No concern
Forage (including herring, Atka mackerel, cod, and pollock)	Stable, heavily monitored	Bycatch levels small relative to forage biomass	No concern
HAPC biota	Low bycatch levels of (spp)	Bycatch levels small relative to HAPC biota	No concern
Marine mammals and birds	Very minor direct-take	Safe	No concern
Sensitive non-target species	Likely minor impact	Data limited, likely to be safe	No concern
Fishery concentration in space and time	Low exploitation rate	Little detrimental effect	No concern
Fishery effects on amount of large size target fish	Low exploitation rate	Natural fluctuation	No concern
Fishery contribution to discards and offal production	Stable trend	Improving, but data limited	Possible concern
Fishery effects on age-at-maturity and fecundity	unknown	NA	Possible concern

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Table 7.1--Rock sole catch from 1977 - September 27, 2003.

Year	Foreign	Joint-Venture	Domestic	Total
1977	5,319			5,319
1978	7,038			7,038
1979	5,874			5,874
1980	6,329	2,469		8,798
1981	3,480	5,541		9,021
1982	3,169	8,674		11,844
1983	4,479	9,140		13,618
1984	10,156	27,523		18,750
1985	6,671	12,079		37,678
1986	3,394	16,217		23,483
1987	776	11,136	28,910	40,046
1988		40,844	45,522	86,366
1989		21,010	47,902	68,912
1990		10,492	24,761	35,253
1991			60,587	60,587
1992			56,998	56,998
1993			63,953	63,953
1994			60,544	60,544
1995			58,870	58,870
1996			46,928	46,928
1997			67,564	67,564
1998			33,645	33,645
1999			40,510	40,510
2000			49,264	49,264
2001			29,255	29,255
2002			41,331	41,331
2003			35,156	35,156

Table 7.2--Discarded and retained rock sole catch, by target fishery, in 2001 and 2002.

		2001	
target fishery	**Discard**	**retained**	**total**
atka mackerel	45	10	54
bottom pollock	189	168	357
Pacific cod	2,920	2,519	5,440
other flatfish	9	30	39
rockfish	2	0	2
flathead sole	849	1,075	1,924
mid water pollock	501	802	1,303
rock sole	3,463	10,866	14,329
sablefish	0	0	0
Greenland turbot	2	0	3
arrowtooth flounder	17	20	37
yellowfin sole	1,959	3,808	5,767
non-retained groundfish	0	0	0
			29,255

		2002	
target fishery	**Discard**	**Retained**	**total**
Atka mackerel	50	26	75
bottom pollock	70	90	160
Pacific cod	4,482	2,343	6,825
other flatfish	128	27	155
rockfish	7	0	7
flathead sole	1,043	709	1,752
mid water pollock	823	896	1,720
rock sole	6,995	13,182	20,177
sablefish	0	0	0
Greenland turbot	1	0	1
arrowtooth flounder	13	8	21
yellowfin sole	4,112	6,326	10,438
non-retained groundfish	0	0	0
			41,331

Table 7.3--Estimated catch numbers at age, 1980-2002 (in thousands).

year/age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1980	0	181	1,506	1,287	3,814	2,191	2,219	1,627	1,544	4,058	2,521	1,332	1,050	1,013	665	169	50	0	0	0
1981	0	0	1,613	2,674	1,527	8,407	1,764	851	1,144	1,839	3,213	1,432	1,237	636	888	516	137	28	0	0
1982	0	257	1,613	2,305	2,256	5,009	8,964	5,569	2,235	2,405	2,761	3,209	2,728	1,493	129	352	133	0	41	0
1983	0	0	4	577	2,033	1,727	3,426	5,684	2,940	3,816	1,502	2,114	5,096	2,501	1,604	1,653	274	165	53	0
1984	0	0	0	2,540	6,889	5,574	11,672	9,182	15,211	9,508	5,396	5,693	8,549	6,187	5,604	4,556	1,285	0	978	0
1985	0	1,470	3,286	11,807	20,807	12,840	8,141	6,531	4,137	5,961	1,024	413	322	727	2,312	1,404	528	413	140	322
1986	0	0	0	499	8,077	17,613	13,113	7,928	9,157	2,831	8,829	1,155	1,140	976	350	902	946	30	0	313
1987	0	0	0	2,071	7,895	13,482	23,226	6,993	5,778	4,502	2,392	6,458	994	267	352	191	673	344	84	718
1988	0	0	573	1,201	34,687	25,798	33,966	21,843	12,973	30,769	6,154	4,768	3,936	3,012	0	628	554	2,532	407	998
1989	0	0	0	1,495	10,113	33,265	16,029	21,434	10,454	10,231	8,697	5,142	4,106	5,286	2,925	1,154	131	0	0	695
1990	0	0	0	233	2,900	7,160	17,828	8,069	10,545	8,781	3,296	1,422	1,901	868	2,400	1,135	253	267	103	1,210
1991	0	18	2,201	7,809	4,570	12,353	17,269	41,194	28,628	19,896	15,885	8,182	3,727	3,514	3,346	3,674	1,136	728	0	1,739
1992	0	0	190	1,017	9,167	9,270	14,680	35,426	32,600	14,008	23,123	11,768	4,635	5,583	2,533	224	6,255	569	534	706
1993	0	0	0	0	0	2,875	11,020	20,443	13,895	60,531	9,742	15,812	12,138	3,354	3,354	1,757	783	1,278	1,597	799
1994	0	0	0	234	0	2,669	16,645	29,411	28,035	28,731	27,852	6,482	9,566	8,190	3,299	2,636	746	116	1,194	0
1995	0	0	0	325	1,188	1,252	6,044	23,427	27,225	17,683	18,867	18,486	7,446	6,752	6,300	180	422	446	0	0
1996	0	0	49	95	419	3,981	3,228	9,103	27,430	22,065	14,249	6,238	7,367	4,843	2,509	10,142	7,206	2,166	49	236
1997	0	9	126	1,849	1,549	3,650	20,448	4,834	21,812	55,524	25,705	21,732	16,669	12,100	6,795	3,554	2,037	1,344	0	0
1998	0	0	0	0	272	338	1,215	5,109	4,450	10,220	31,567	15,830	6,707	6,525	2,552	1,181	1,655	1,145	112	236
1999	0	0	0	0	1,235	1,185	3,085	1,774	13,337	6,469	13,330	38,859	12,458	6,245	6,609	1,239	374	497	82	640
2000	0	0	0	0	304	970	1,873	3,289	8,431	26,140	9,296	11,979	32,324	13,049	6,887	4,048	2,564	500	1,004	158
2001	0	0	0	0	1,036	2,026	2,658	3,778	3,719	7,280	15,846	6,796	7,574	12,065	6,673	1,907	1,753	462	205	273
2002	0	0	0	195	520	3,909	3,784	3,536	9,758	7,530	10,543	18,408	7,241	5,984	16,007	7,214	2,607	3,101	772	298

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Table 7-4 --Rock sole weight-at-age (grams) by age and year determined from 1980-2000 from length-at-age and length-weight relationships from the annual trawl survey in the eastern Bering Sea.

	1	2	3	4	5	6	7	8	9	10	11	12	11	12	13	14	15	16	17	18	19	20
1980	0	6	31	76	135	202	274	344	409	471	523	572	523	572	613	646	677	703	727	745	764	777
1981	0	6	31	76	135	202	274	344	409	471	523	572	523	572	613	646	677	703	727	745	764	777
1982	0	18	56	87	106	164	215	271	338	395	466	415	466	415	522	544	725	763	742	742	742	742
1983	0	17	35	109	160	195	261	296	357	369	400	406	400	406	513	531	588	655	835	948	865	865
1984	0	19	30	64	141	187	248	306	365	424	480	450	480	450	496	628	466	588	727	727	727	727
1985	0	16	32	54	113	197	264	325	363	469	468	650	468	650	556	477	654	595	556	604	785	807
1986	0	19	32	46	110	198	307	346	383	431	475	483	475	483	541	502	616	693	652	795	795	795
1987	0	15	36	74	120	212	331	447	450	421	498	522	498	522	543	612	486	682	701	746	696	696
1988	0	17	29	55	127	202	302	400	415	520	524	565	524	565	508	615	611	679	643	659	654	654
1989	0	16	27	58	106	184	246	373	439	518	521	515	521	515	511	605	594	566	703	703	682	703
1990	0	9	17	41	83	151	243	345	409	473	524	559	524	559	536	609	648	755	755	743	743	743
1991	0	13	17	36	77	126	198	296	345	432	493	541	493	541	603	611	690	751	751	696	622	688
1992	0	10	18	39	64	105	188	239	320	382	429	488	429	488	527	537	565	596	709	709	709	709
1993	0	9	24	38	85	114	184	220	314	399	496	547	496	547	565	564	609	661	661	661	739	739
1994	0	12	26	50	79	111	176	233	302	378	407	484	407	484	512	574	538	599	791	700	644	644
1995	0	12	26	43	79	123	172	236	289	418	442	500	442	500	720	706	672	833	833	752	752	790
1996	0	8	24	55	80	135	180	250	271	327	418	454	418	454	434	551	514	610	705	659	770	722
1997	0	8	23	49	86	120	178	223	250	318	363	382	363	382	443	513	577	529	546	695	695	695
1998	0	8	23	49	86	120	178	223	250	318	363	382	363	382	443	513	577	529	546	695	695	695
1999	0	8	23	49	86	120	178	223	250	318	363	382	363	382	443	513	577	529	546	695	695	695
2000	0	8	23	49	86	120	178	223	250	318	363	382	363	382	443	513	577	529	546	695	695	695

Table 7-5.--Mean length-at-age (cm) and proportion mature for female Bering Sea rock sole from observer anatomical scans during the 1993-94 fishing seasons.

Age	Length-at-age	Proportion mature
1	4.0	0
2	8.2	0.006
3	14.3	0.003
4	19.4	0.012
5	23.6	0.039
6	27.1	0.098
7	30.1	0.198
8	32.6	0.330
9	34.6	0.470
10	36.4	0.590
11	37.8	0.680
12	39.0	0.746
13	40.0	0.795
14	40.8	0.830
15	41.5	0.856
16	42.1	0.875
17	42.6	0.889
18	43.0	0.900
19	43.4	0.908
20	43.7	0.915

Table 7.6--Estimated population numbers-at-age (millions) from the annual Bering Sea trawl surveys, 1982- 2002.

year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1982	0	226	253	491	536	527	530	245	83	74	62	109	62	25	6	8	8	0	1	0
1983	0	70	668	553	633	313	313	354	162	136	53	72	99	52	36	24	4	2	1	0
1984	0	155	469	1,058	666	367	588	258	323	128	52	57	65	39	51	23	9	0	2	3
1985	0	165	413	1,129	1,128	523	321	247	141	158	36	15	7	17	44	37	8	8	2	2
1986	0	117	596	1,299	1,384	1,214	533	288	277	53	202	21	21	21	0	21	21	0	0	11
1987	0	64	752	1,074	1,149	902	1,030	269	269	172	75	215	32	11	11	0	0	0	0	0
1988	0	335	1,104	1,468	1,931	974	923	505	307	66	164	88	70	58	0	6	11	58	23	8
1989	0	131	867	989	1,136	1,304	749	557	414	129	92	94	68	81	26	24	2	2	17	15
1990	0	2,985	4,733	2,497	1,352	1,650	490	670	457	191	84	95	25	59	2	0	11	0	37	0
1991	0	27	168	3,633	2,308	1,338	973	848	508	355	229	151	71	56	33	14	0	44	0	0
1992	0	9	244	658	2,946	2,283	868	1,057	506	300	298	185	131	91	46	25	13	0	11	0
1993	0	45	995	1,384	1,251	3,957	2,181	1,020	958	540	161	149	147	97	48	10	0	0	5	10
1994	0	43	508	2,184	1,356	1,365	4,533	2,240	1,075	348	664	295	167	190	90	55	14	11	29	16
1995	0	0	140	850	1,846	848	727	2,228	1,255	508	462	393	111	134	92	3	9	2	2	10
1996	0	38	956	435	687	1,832	539	901	2,133	1,270	369	191	231	69	97	85	32	11	1	9
1997	0	4	573	1,528	552	904	2,558	523	948	2,041	783	578	373	281	119	125	55	29	0	14
1998	0	2	234	654	763	532	834	1,607	495	525	1,426	923	304	108	134	46	29	8	11	19
1999	0	1	64	105	295	835	116	622	1,470	829	584	1,376	529	238	112	123	27	27	11	2
2000	0	0	41	503	237	377	872	358	960	1,416	741	639	1,054	442	240	207	60	9	12	14
2001	0	28	228	242	633	434	366	916	501	1,199	1,137	515	657	1,039	396	183	64	58	19	4
2002	0	150	390	235	240	734	270	225	630	326	514	995	325	218	781	266	97	110	4	24

Table 7.7--Key equations used in the population dynamics model.

Equation	Description
$N_{t,1} = R_t = R_0 e^{\tau_t}, \quad \tau_t \sim N(0,\delta^2{}_R)$	Recruitment 1956-75
$N_{t,1} = R_t = R_\gamma e^{\tau_t}, \quad \tau_t \sim N(0,\delta^2{}_R)$	Recruitment 1976-96
$C_{t,a} = \frac{F_{t,a}}{Z_{t,a}}\left(1 - e^{-z_{t,a}}\right)N_{t,a}$	Catch in year *t* for age *a* fish
$N_{t+1,a+1} = N_{t,a}e^{-z_{t,a}}$	Numbers of fish in year *t+1* at age *a*
$N_{t+1,A} = N_{t,A-1}e^{-z_{t,A-1}} + N_{t,A}e^{-z_{t,A}}$	Numbers of fish in the "plus group"
$S_t = \sum N_{t,a}W_{t,a}\phi_a$	Spawning biomass
$Z_{t,a} = F_{t,a} + M$	Total mortality in year *t* at age *a*
$F_{t,a} = s_a \mu^F \exp^{\varepsilon^F{}_t}, \quad \varepsilon^F{}_t \sim N(o,\sigma^{2_F})$	Fishing mortality
$s_a = \frac{1}{1 + \left(e^{-\alpha + \beta a}\right)}$	Age-specific fishing selectivity
$C_t = \sum C_{t,a}$	Total catch in numbers
$P_{t,a} = {C_{t,a}}/{C_t}$	Proportion at age in catch
$SurB_t = q\sum N_{t,a}W_{t,a}v_a$	Survey biomass
$L = \sum_{t,a} m_t p_{t,a} \ln \frac{\hat{p}_{t,a}}{p_{t,a}} + (-0.5)\sum_t \left[\left(\ln \frac{surB_t}{\hat{surB}_t} {1}/{\sigma_t}\right)^2 - \ln \sigma_t\right]$	Total log likelihood

Table 7.8--Variables used in the population dynamics model.

Variables	
R_t	Age 1 recruitment in year t
R_0	Geometric mean value of age 1 recruitment, 1956-75
R_γ	Geometric mean value of age 1 recruitment, 1976-96
τ_t	Recruitment deviation in year t
$N_{t,a}$	Number of fish in year t at age a
$C_{t,a}$	Catch numbers of fish in year t at age a
$P_{t,a}$	Proportion of the numbers of fish age a in year t
C_t	Total catch numbers in year t
$W_{t,a}$	Mean body weight (kg) of fish age a in year t
ϕ_a	Proportion of mature females at age a
$F_{t,a}$	Instantaneous annual fishing mortality of age a fish in year t
M	Instantaneous natural mortality, assumed constant over all ages and years
$Z_{t,a}$	Instantaneous total mortality for age a fish in year t
s_a	Age-specific fishing gear selectivity
μ^F	Median year-effect of fishing mortality
ε_t^F	The residual year-effect of fishing mortality
ν_a	Age-specific survey selectivity
α	Slope parameter in the logistic selectivity equation
β	Age at 50% selectivity parameter in the logistic selectivity equation
σ_t	Standard error of the survey biomass in year t

Table 7.9--Model estimates of rock sole fishing mortality and exploitation rate (catch/total biomass).

year	Full selection F	Exploitation rate
1975	0.158	0.061
1976	0.119	0.049
1977	0.055	0.025
1978	0.064	0.030
1979	0.048	0.022
1980	0.068	0.029
1981	0.065	0.026
1982	0.092	0.031
1983	0.091	0.027
1984	0.233	0.068
1985	0.097	0.029
1986	0.100	0.029
1987	0.081	0.024
1988	0.162	0.050
1989	0.096	0.032
1990	0.111	0.043
1991	0.095	0.039
1992	0.102	0.043
1993	0.075	0.034
1994	0.064	0.031
1995	0.043	0.024
1996	0.063	0.036
1997	0.031	0.019
1998	0.035	0.024
1999	0.043	0.031
2000	0.026	0.019
2001	0.037	0.028
2002	0.040	0.031

Table 7.10 --Model estimates of rock sole age-specific fishery and survey selectivities.

Age	Fishery (1980-2002)	Survey (1982-2002)
1	0	0.01
2	0	0.06
3	0.01	0.26
4	0.03	0.66
5	0.06	0.92
6	0.13	0.98
7	0.27	1.0
8	0.47	1.0
9	0.68	1.0
10	0.84	1.0
11	0.93	1.0
12	0.97	1.0
13	0.99	1.0
14	0.99	1.0
15	0.99	1.0
16	0.99	1.0
17	0.99	1.0
18	0.99	1.0
19	0.99	1.0
20	0.99	1.0

Table 7-11.--Model estimates of rock sole age 2+ total biomass and female spawning biomass from the 2002 and 2003 assessments.

	2003 Assessment		2002 Assessment	
	Age 2+ Total biomass	Female Spawning biomass	Age 2+ Total biomass	Female Spawning biomass
1975	196,345	33,594	177,406	30,655
1976	203,931	36,210	182,524	32,581
1977	215,388	40,272	191,228	35,847
1978	238,186	45,966	210,339	40,709
1979	265,944	50,625	233,338	44,560
1980	302,326	55,207	263,667	48,351
1981	344,333	59,320	297,996	51,566
1982	384,665	55,532	329,142	47,901
1983	497,186	63,875	421,910	54,533
1984	550,563	73,127	464,301	61,869
1985	646,295	81,880	537,825	67,380
1986	810,265	98,918	671,693	80,790
1987	1,104,260	132,896	913,285	108,098
1988	1,265,170	165,574	1,043,510	134,326
1989	1,400,590	191,825	1,144,530	153,507
1990	1,412,600	226,630	1,148,240	180,387
1991	1,457,740	248,703	1,211,080	206,629
1992	1,475,250	261,911	1,209,390	214,434
1993	1,718,950	322,882	1,401,210	263,686
1994	1,796,710	358,682	1,443,010	288,406
1995	1,976,890	458,475	1,568,250	363,990
1996	1,862,410	452,194	1,457,880	354,913
1997	1,725,830	459,089	1,353,620	362,800
1998	1,692,120	489,123	1,280,970	371,385
1999	1,594,390	494,839	1,201,030	374,683
2000	1,518,380	497,226	1,137,970	375,130
2001	1,451,040	496,572	1,056,180	363,614
2002	1,338,580	470,022	969,681	344,009
2003	1,231,270	432,515		

Table 7.12--Estimated age 4 recruitment of rock sole (thousands of fish) from the 2002 and 2003 assessments.

Year class	2003 Assessment	2002 Assessment
1971	126,729	112,192
1972	104,485	92,153
1973	138,596	121,833
1974	188,181	164,660
1975	494,410	429,466
1976	277,969	239,297
1977	419,556	356,104
1978	477,320	401,834
1979	605,205	506,963
1980	1,169,670	980,267
1981	1,187,510	991,312
1982	1,044,110	871,754
1983	1,863,690	1,563,010
1984	1,508,480	1,248,960
1985	1,497,240	1,245,960
1986	2,372,510	1,954,020
1987	4,028,470	3,273,260
1988	1,454,210	1,186,240
1989	1,001,270	778,121
1990	2,188,630	1,679,070
1991	978,521	731,282
1992	507,763	351,992
1993	929,679	694,307
1994	446,254	348,939
1995	321,718	215,753
1996	511,462	295,968
1997	216,950	

Table 7.13--Projections of rock sole female spawning biomass (1,000s t), future catch (1,000s t) and full selection fishing mortality rates for seven future harvest scenarios.

Scenarios 1 and 2

Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2003	424.628	40.000	0.043
2004	390.665	**139.318**	0.173
2005	323.582	114.396	0.173
2006	260.574	92.172	0.173
2007	215.880	77.113	0.173
2008	188.127	66.668	0.169
2009	169.346	55.360	0.151
2010	162.229	52.081	0.144
2011	161.998	53.029	0.143
2012	164.891	55.706	0.145
2013	171.241	59.893	0.148
2014	178.012	63.867	0.151
2015	183.002	66.635	0.153
2016	187.242	68.858	0.155

Scenario 3

1/2 Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2003	424.628	40.000	0.043
2004	393.352	72.407	0.087
2005	352.973	64.325	0.087
2006	306.295	55.691	0.087
2007	270.759	49.455	0.087
2008	248.442	45.878	0.087
2009	230.217	43.244	0.087
2010	220.559	42.197	0.087
2011	217.736	42.346	0.087
2012	218.092	42.868	0.086
2013	223.767	44.237	0.086
2014	231.585	45.949	0.085
2015	238.022	47.311	0.085
2016	244.427	48.598	0.085

Scenario 4

Harvest at average F over the past 5 years

Year	Female spawning biomass	catch	F
2003	424.628	40.000	0.043
2004	394.921	31.040	0.036
2005	371.301	28.873	0.036
2006	336.691	26.085	0.036
2007	309.577	24.034	0.036
2008	293.742	22.976	0.036
2009	279.078	22.117	0.036
2010	271.778	21.857	0.036
2011	271.144	22.104	0.036
2012	272.854	22.533	0.036
2013	280.490	23.382	0.036
2014	290.858	24.361	0.036
2015	299.360	25.135	0.036
2016	308.017	25.877	0.036

Scenario 5

No fishing

Year	Female spawning biomass	catch	F
2003	424.628	0	0
2004	396.057	0	0
2005	385.130	0	0
2006	360.579	0	0
2007	341.325	0	0
2008	332.240	0	0
2009	322.097	0	0
2010	318.325	0	0
2011	321.074	0	0
2012	325.276	0	0
2013	335.865	0	0
2014	349.708	0	0
2015	361.108	0	0
2016	372.770	0	0

Table 7.13—continued.

Scenario 6

Determination of whether rock sole are currently overfished **B35=177.34**

Year	Female spawning biomass	catch	F
2003	424.628	40.000	0.043
2004	389.522	**166.358**	0.210
2005	311.800	132.096	0.210
2006	243.293	103.276	0.210
2007	196.296	84.366	0.210
2008	168.010	64.284	0.182
2009	152.381	54.292	0.164
2010	147.611	52.347	0.158
2011	148.906	54.618	0.159
2012	152.808	58.593	0.163
2013	159.376	64.005	0.169
2014	165.721	68.683	0.174
2015	170.081	71.779	0.177
2016	173.500	74.073	0.179

Scenario 7

Determination of whether rock sole are approaching an overfished condition **B35=177.34**

Year	Female spawning biomass	catch	F
2003	424.628	40.000	0.043
2004	390.665	139.318	0.173
2005	323.582	114.396	0.173
2006	259.827	110.109	0.210
2007	208.453	89.341	0.210
2008	176.940	71.008	0.192
2009	157.769	57.985	0.170
2010	150.874	54.493	0.162
2011	150.852	55.864	0.161
2012	153.872	59.248	0.164
2013	159.887	64.290	0.169
2014	165.915	68.767	0.174
2015	170.107	71.766	0.177
2016	173.455	74.025	0.179

Table 7.14—Catch and bycatch in the rock sole target fisheries, 1991-2002, from blend of regional office reported catch and observer sampling.

Species	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Grand Total
Walleye Pollock	9,711	9,825	18,583	15,784	7,766	7,698	9,123	3,955	5,207	5,481	4,577	9,942	107,654
Arrowtooth Flounder	254	473	1,143	1,782	507	1,341	411	300	69	216	835	314	7,645
Pacific Cod	4,262	4,651	8,160	6,358	9,796	6,965	8,947	3,529	3,316	4,219	3,391	4,366	67,958
Groundfish, General	1,693	3,000	3,091	3,266	1,605	1,581	1,381	909	537	1,186	1,198	692	20,140
Rock Sole	22,067	24,873	39,857	40,139	29,241	18,380	32,477	13,092	16,047	29,042	14,437	20,168	299,820
Flathead Sole			2,140	1,702	1,147	1,302	2,373	1,223	575	1,806	1,051	771	14,090
Sablefish	9	0	4	16	3	3	1	0	2	5	12	4	60
Atka Mackerel	3	10	15	0		0	0	9	0	38	3	0	78
Pacific Ocean Perch	37	10	15	62	4	2		1	0	0	0	0	132
Rex Sole			79	145	108	48	11	12	5	4	18	7	438
Flounder, General	2,610	4,550	2,221	2,756	1,636	1,591	1,498	342	362	1,184	726	307	19,783
Squid		0	0	0							0		0
Dover Sole				0									0
Thornyhead				8									8
Shortraker/Rougheye	8	0	2	21				1					31
Butter Sole			38	11	1	5	79	53	38	156	72	94	548
Unsp. pelagic rockfish				5									5
Rougheye Rockfish			0		0								0
Starry Flounder			230	85	0	1	99	72	34	214	152	329	1,215
Northern Rockfish				29					2			1	32
Dusky Rockfish						0				0			0

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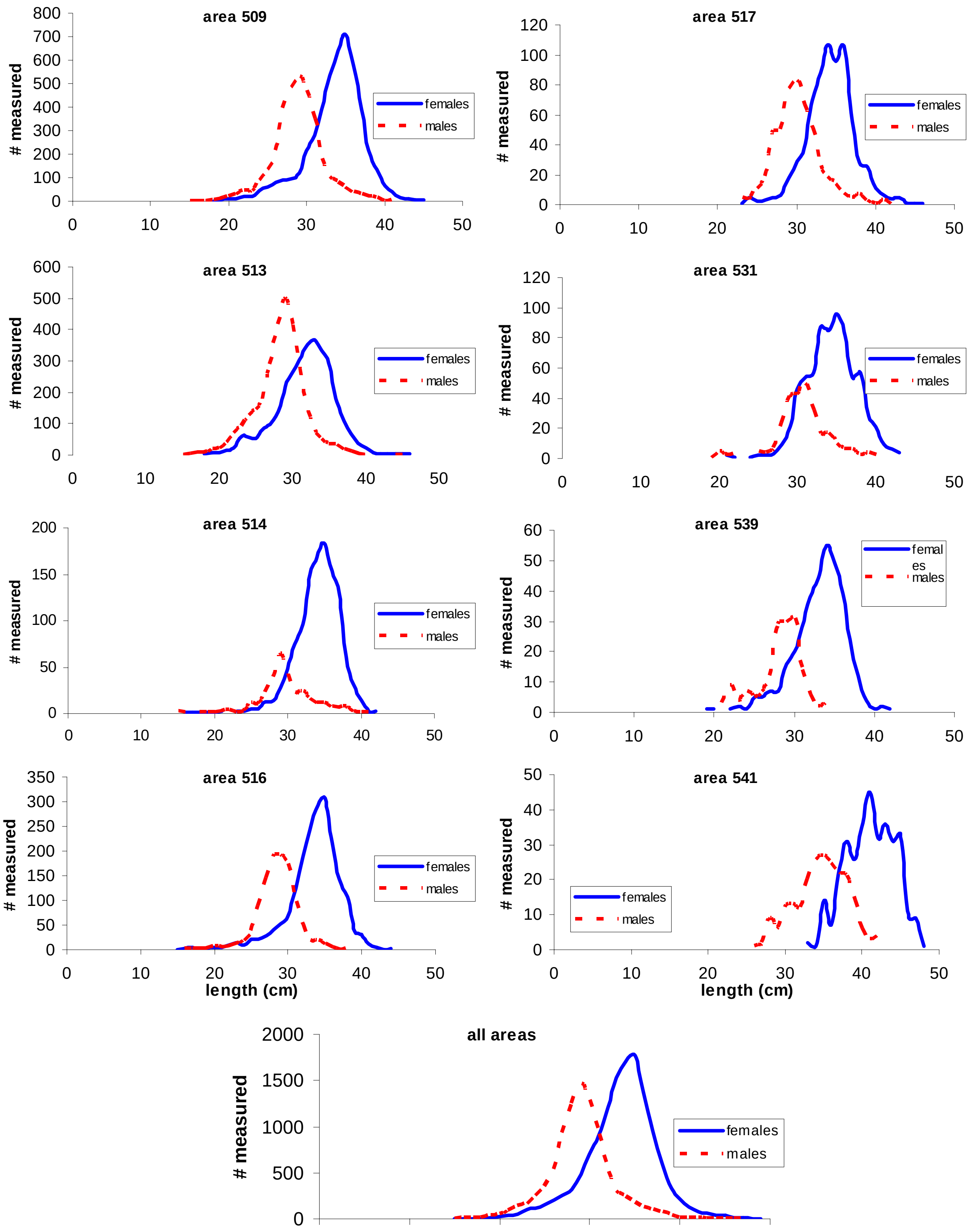
Yellowfin Sole	2,043	4,069	6,277	5,690	6,876	6,030	7,601	1,358	1,421	2,976	3,951	3,777	52,069
English Sole			1							0			1
Black Rockfish			4										4
Greenland Turbot	1	3	28	50	3	3	2	1	0	1	15	0	108
Alaska Plaice			2,561	931	173	71	408	250	63	385	75	621	5,538
Sculpin, General										9	2	271	282
Skate, General										1	5	306	312
Sand Sole					4	1	122	17			10	25	179
Greenstriped Rockfish									0				0
Copper Rockfish												1	1
Rockfish, General	0	0		0	5	1	0	1	0	15	4		27
Octopus										1		0	1
Chilipepper										13			13
Eels											0	0	0
Lingcod							1			0			1
Lumpsucker			26										26
Jellyfish (unspecified)										27	68	80	175
Snails										0	1		1
Sea cucumber			105								0		105
Korean horsehair crab										0			0
Pacific sandfish										0			0
Grand Total	42,699	51,464	84,581	78,839	58,875	45,024	64,534	25,125	27,680	46,980	30,606	42,077	598,483

NPFMC Bering Sea/Aleutian Islands SAFE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measured
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700
600
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400
300
200
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area 517
measured
120
100
80
60
40
20
0
females
males
area 513
600
500
400
300
200
100
area 531
area 514
200
150
100
50
area 539
60
50
40
30
20
10
femal
es
males
area 516
350
300
250
200
150
100
50
length (cm)
area 541
50
40
30
20
10
length (cm)
all areas
2000
1500
1000
500
0
measured
females
males

Figure 7.1—Size composition of rock sole, by sex and area, in the 2002 catch as determined from observer sampling.

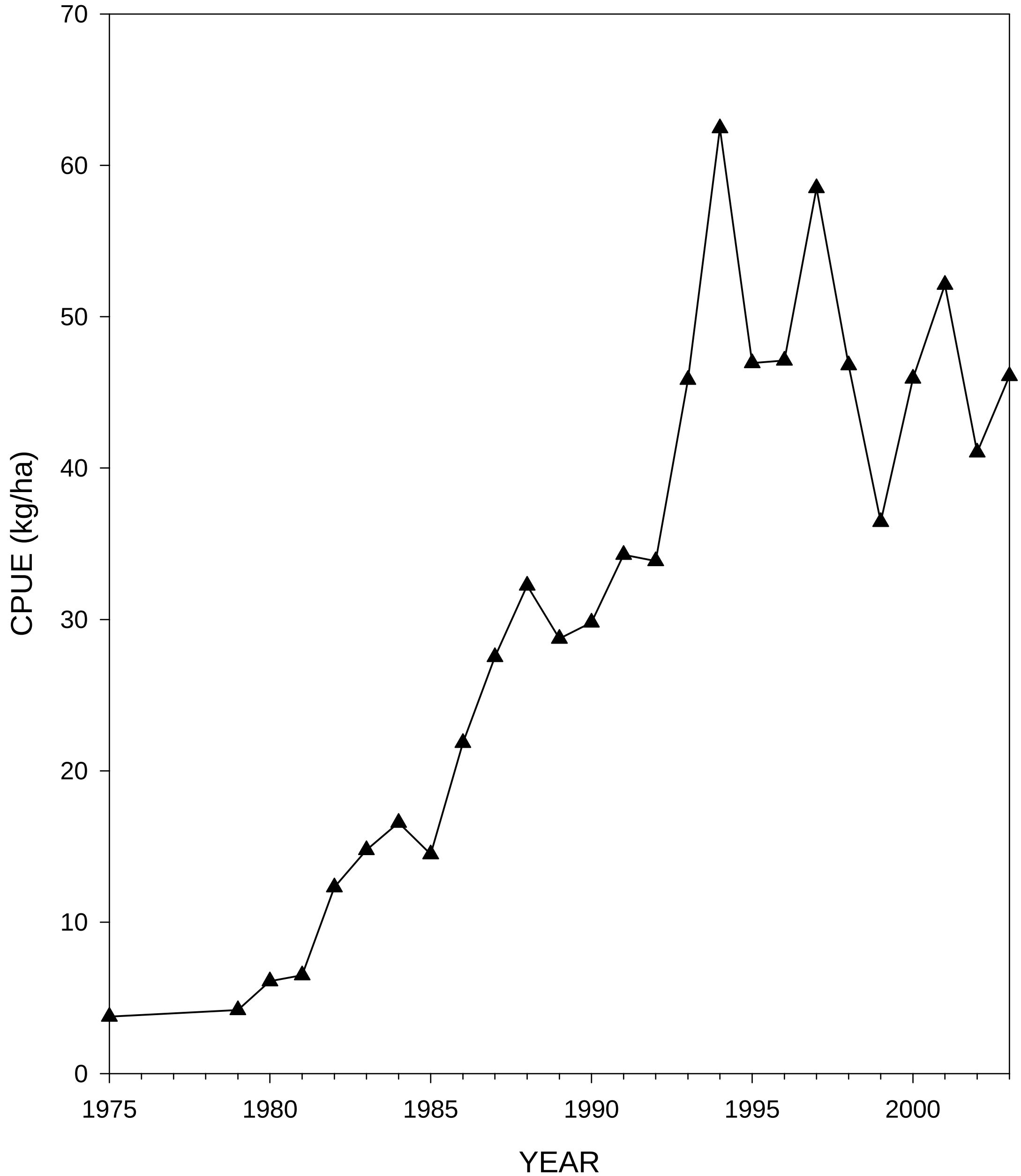

Figure 7.2- Relative abundance (catch per unit effort, CPUE) for rock sole from Alaska Fisheries Science Center bottom trawl survey.

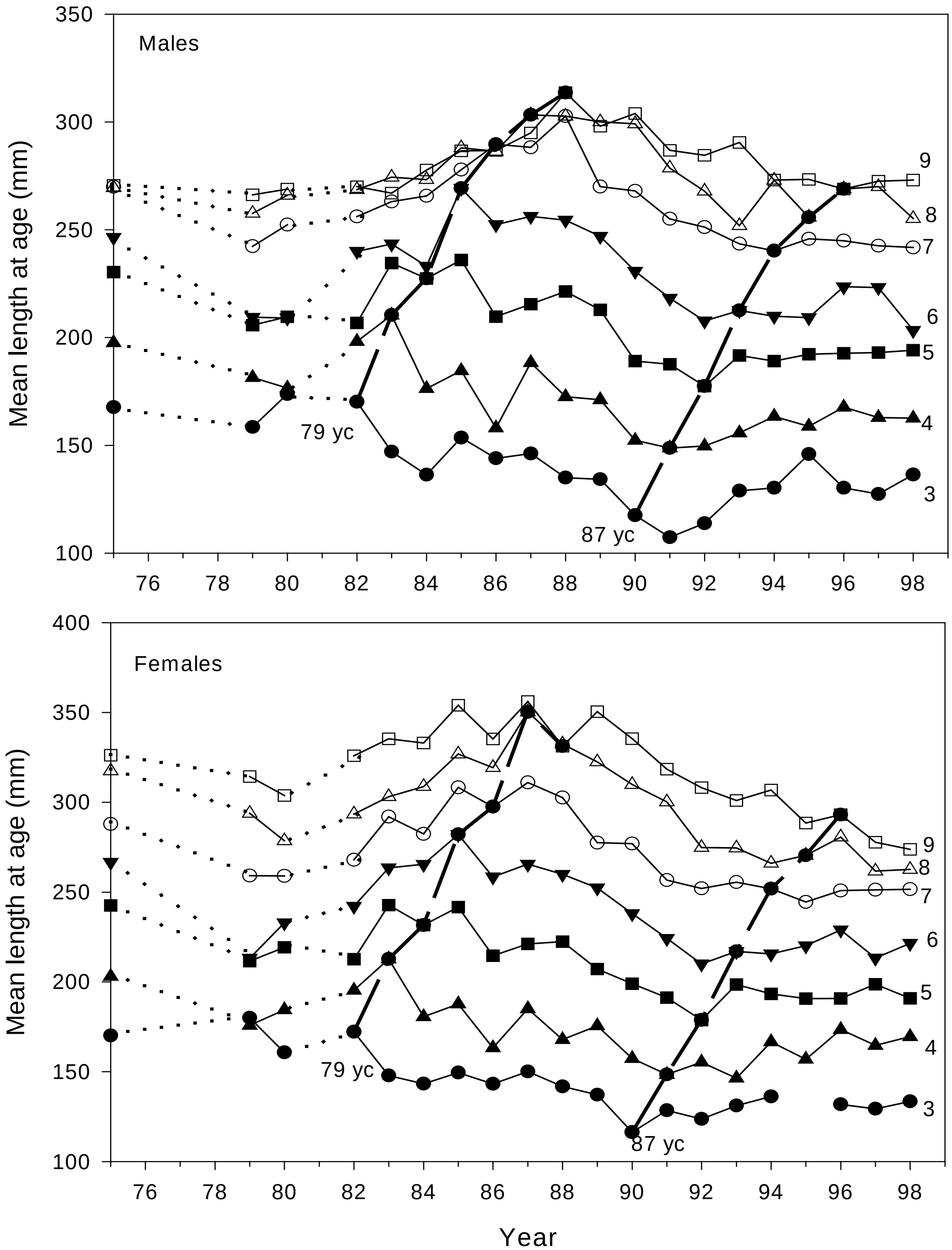

Fig. 7.3. Mean lengths at age (mm) by year of survey for eastern Bering Sea northern rocksole ages 3-9 for each sex during 1975-1998. Growth curves are shown for the 1979 (79yc) and 1987 (87yc) year classes. Dotted lines indicate no data during the period.

(From Walters and Wilderbuer, 2000, p.20)

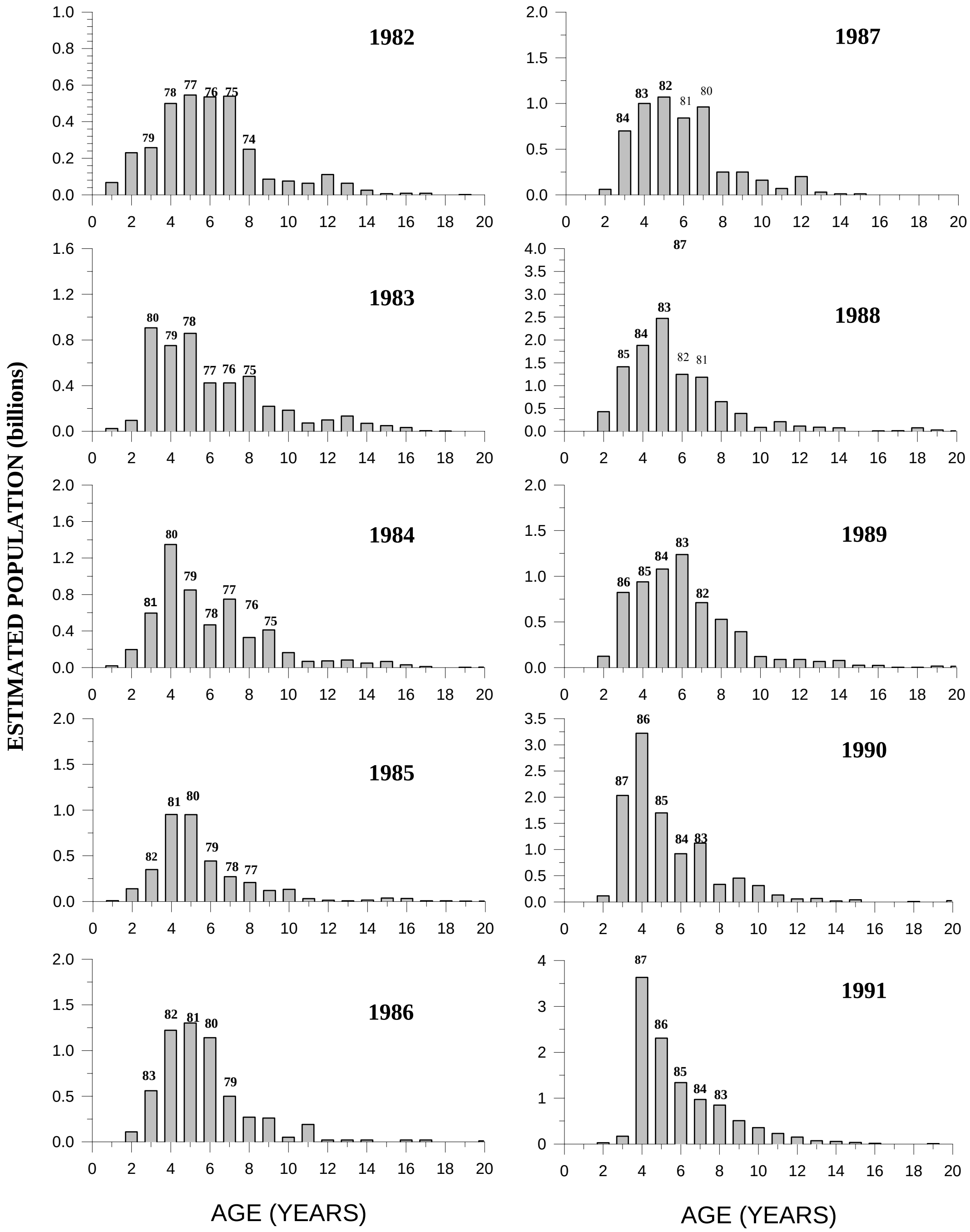

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Figure 6.3- Age composition of rock sole as shown by data collected on Alaska Fisheries Science Center demersal trawl surveys.

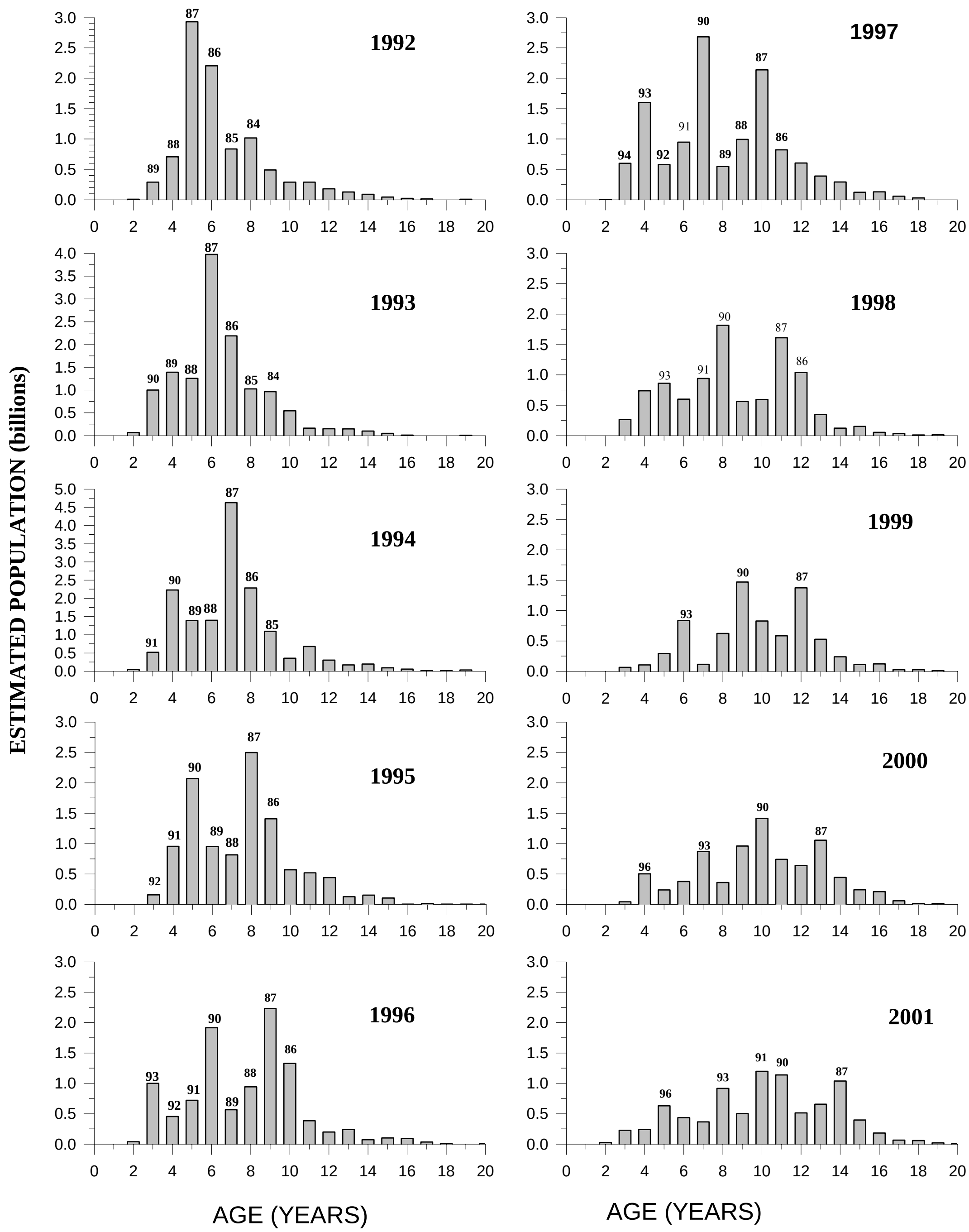


Figure 7.4-(continued)

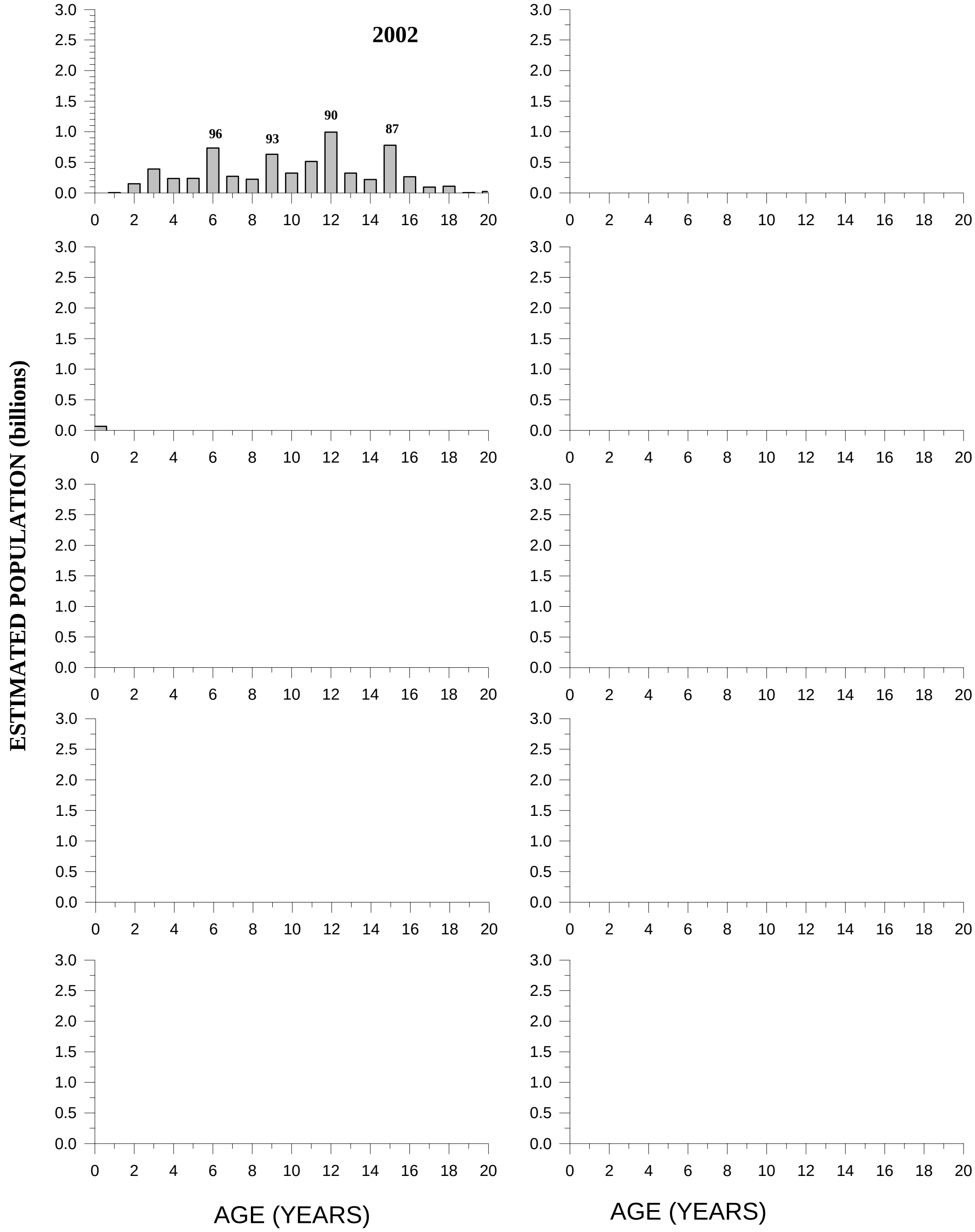


Figure 7.4-(continued)

Figure 6.5--Model fit to various data components and the total-log(likelihood) by ranged fixed q values from 1.0 to 2.2 with natural mortality fixed at 0.18 and selectivity estimated.

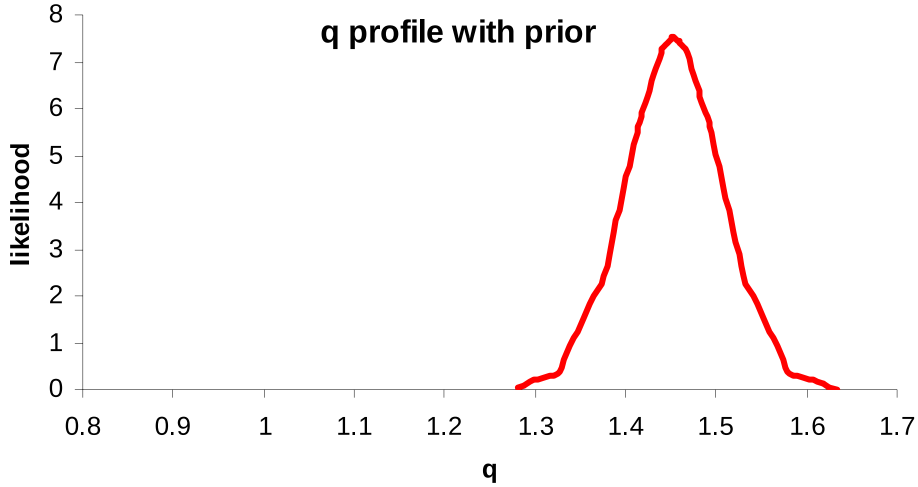


Figure 7.5-- The profile likelihood of survey catchability (q) for rock sole given the observed data

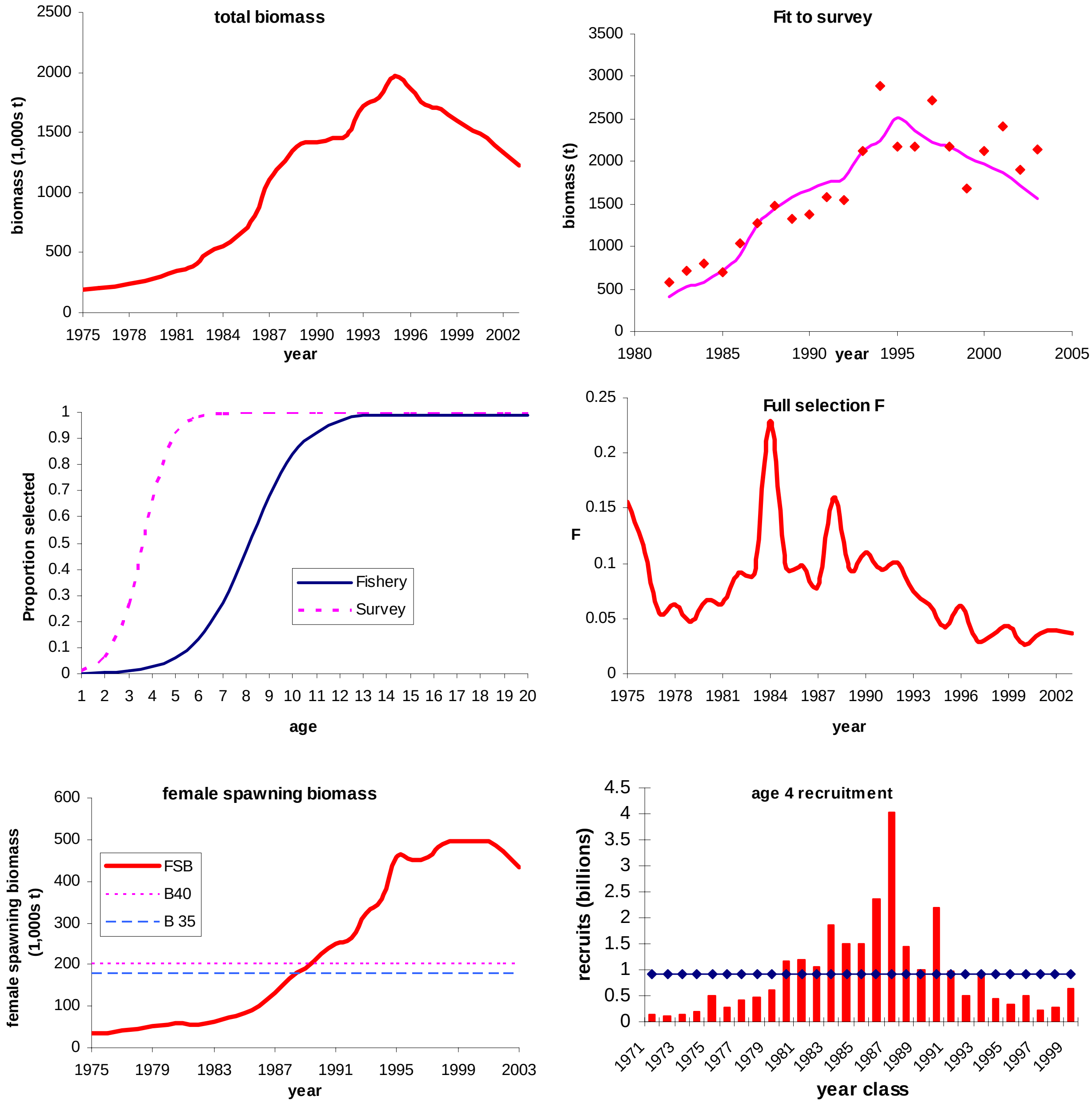


Figure 7.6--Stock assessment model estimates of total 2+ biomass (top left panel), fit to trawl survey biomass (top right panel), age-specific fishery and survey selectivity (middle left panel) and average annual fishing mortality rate (middle right panel), female spawning biomass (bottom right panel) and estimated age 4 recruitment (bottom right panel)..

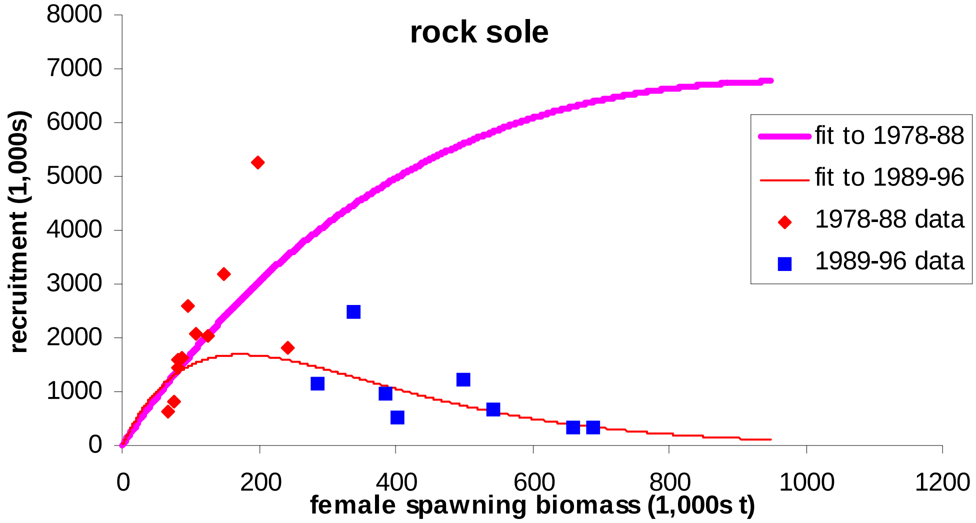


Figure 7.7--Ricker (1958) model fit to spawner-recruit estimates from two decades with different productivity.

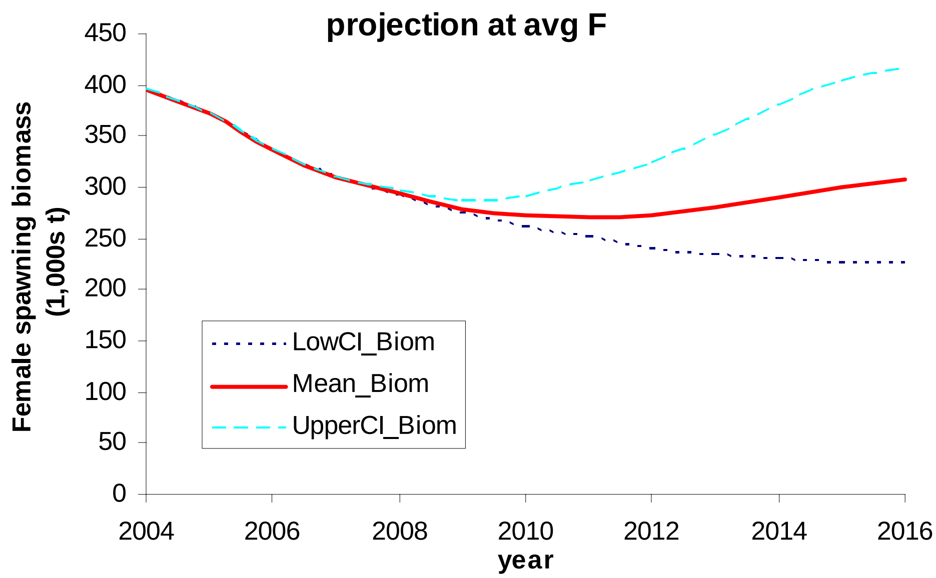


Figure 7.8—Projection of rock sole female spawning biomass when fishing in the future at the average F of the past five years.

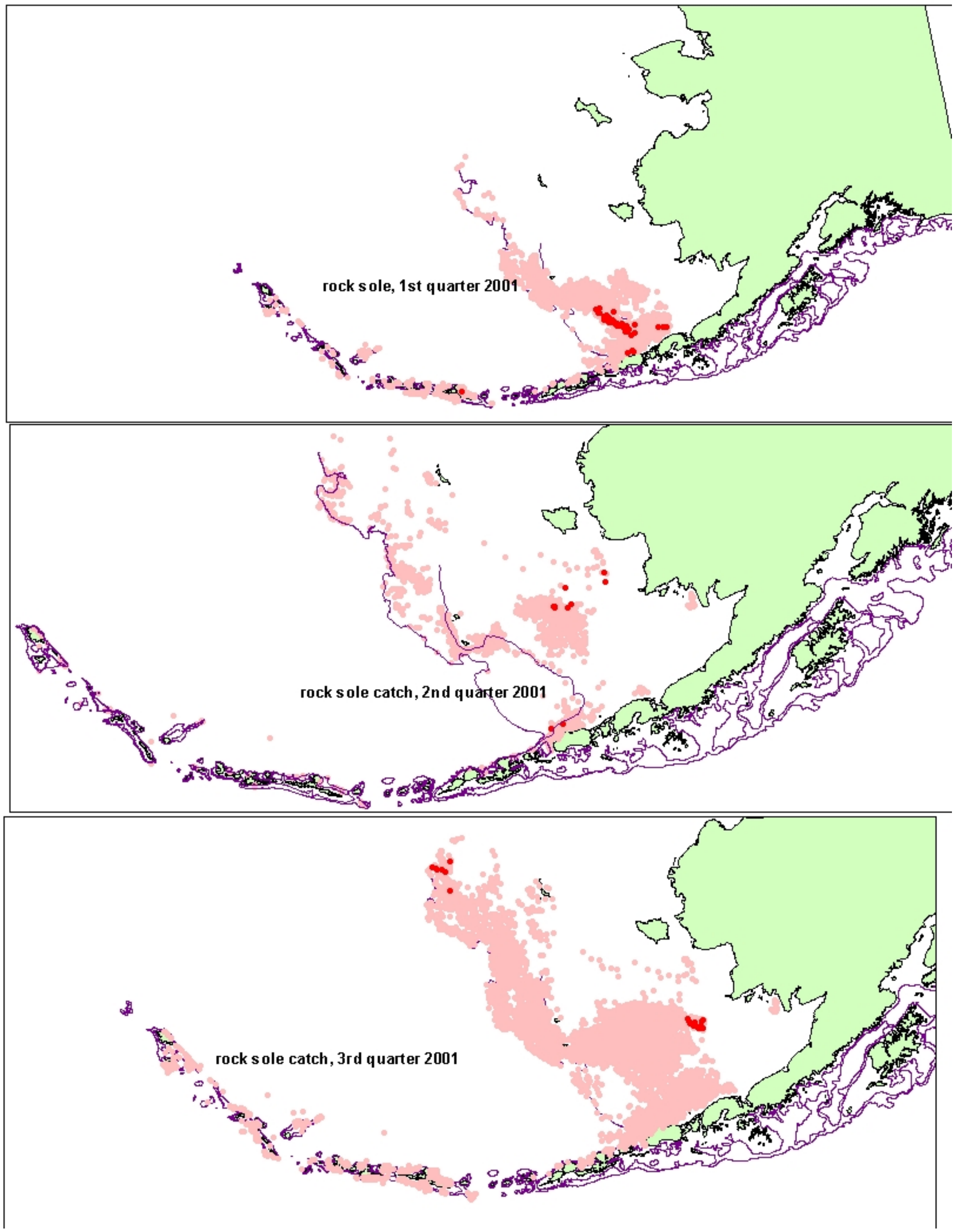
Appendix

1) Observed fishery trawl locations, by quarter, for the 2001 fishing season. Trawl locations where rock sole comprised 20% or more of the catch are identified by darker circles.

2) Figures showing the fit of the stock assessment model to the time-series of fishery and trawl survey age compositions (survey and fishery observations are the solid lines).

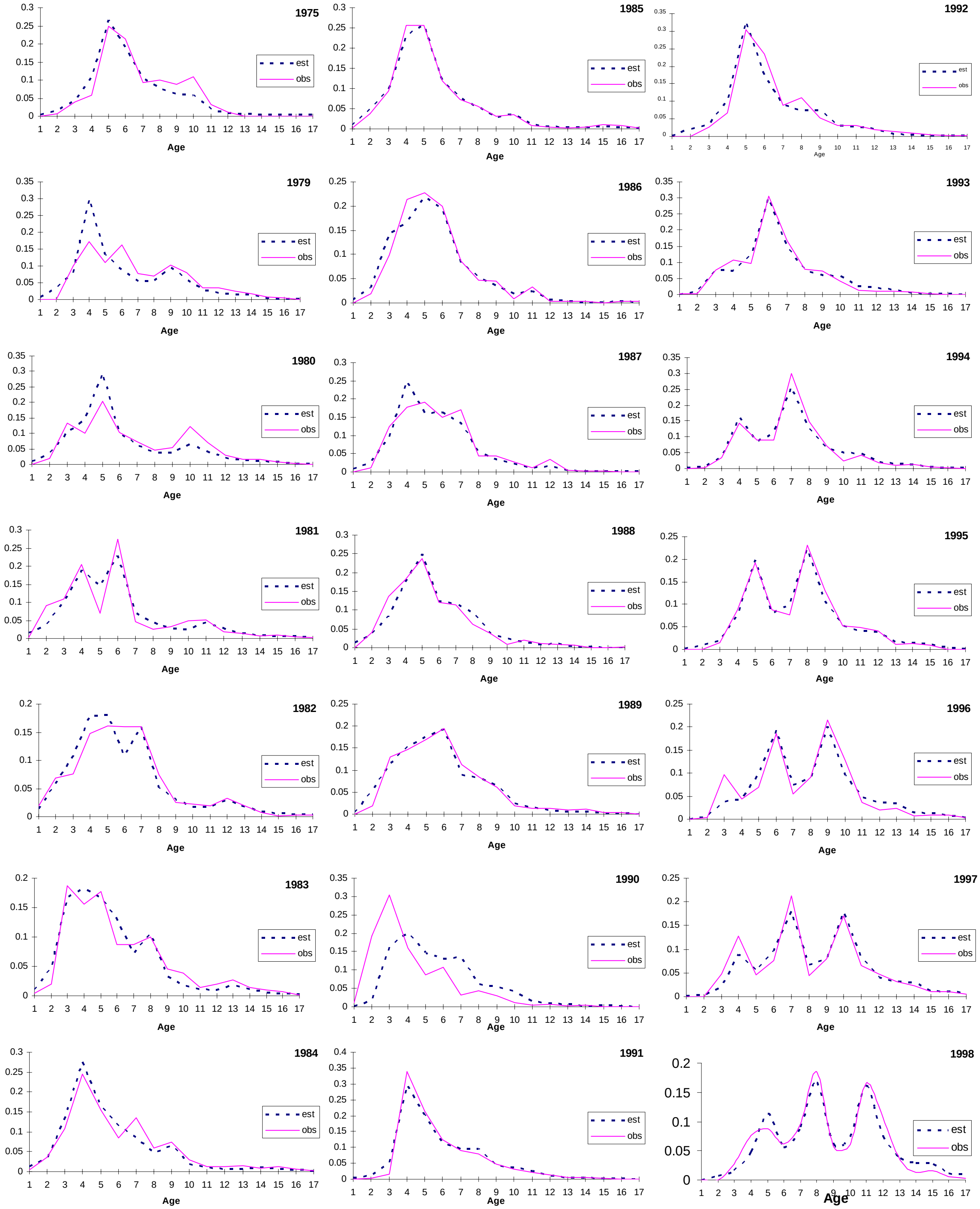
3) Table of the assessment model estimates of population numbers at age 1975- 2002.

4) Table of total population removals of rock sole from Alaska Fisheries Science Center research activities, 1977-

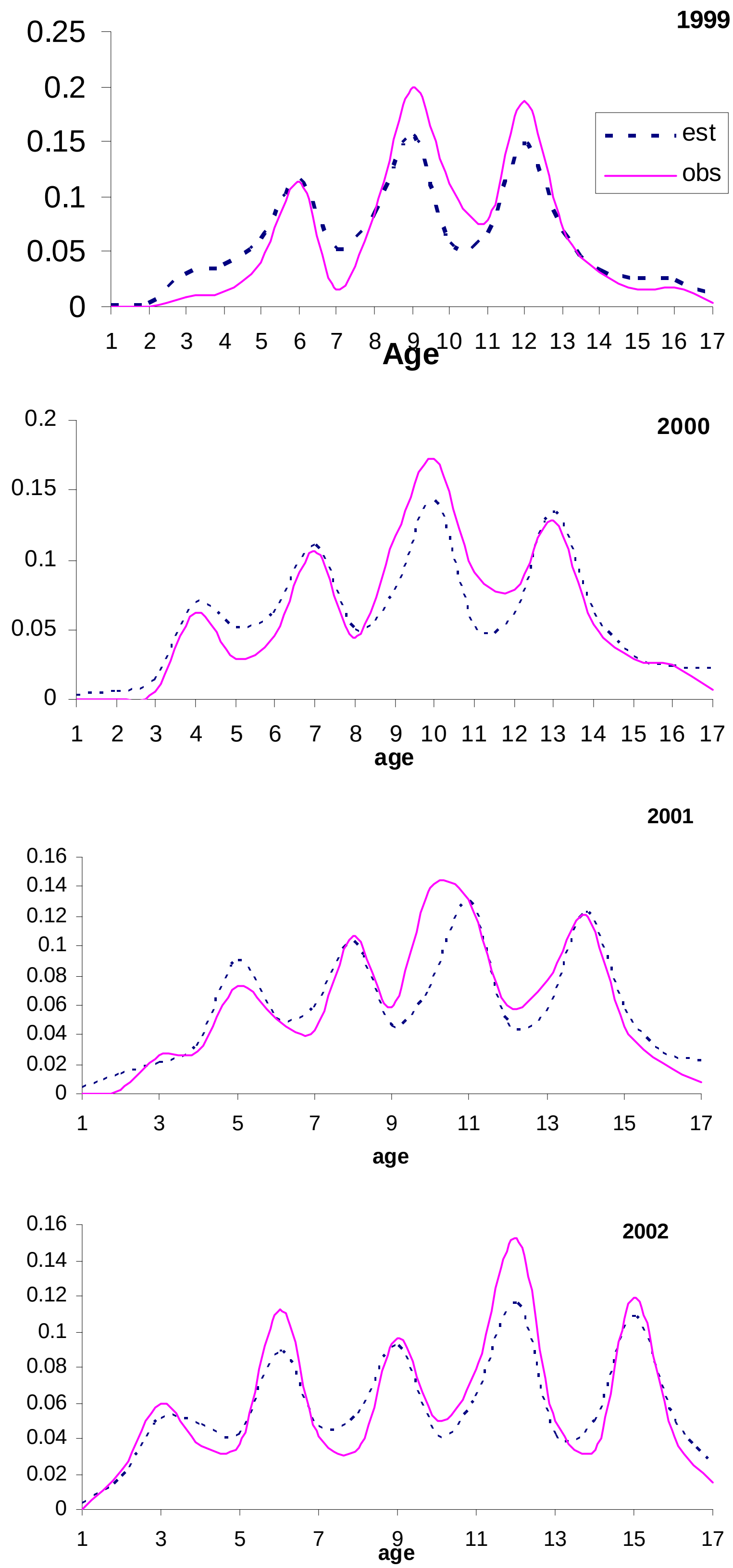


2002.

Fits to the survey age composition



Fits to the survey age composition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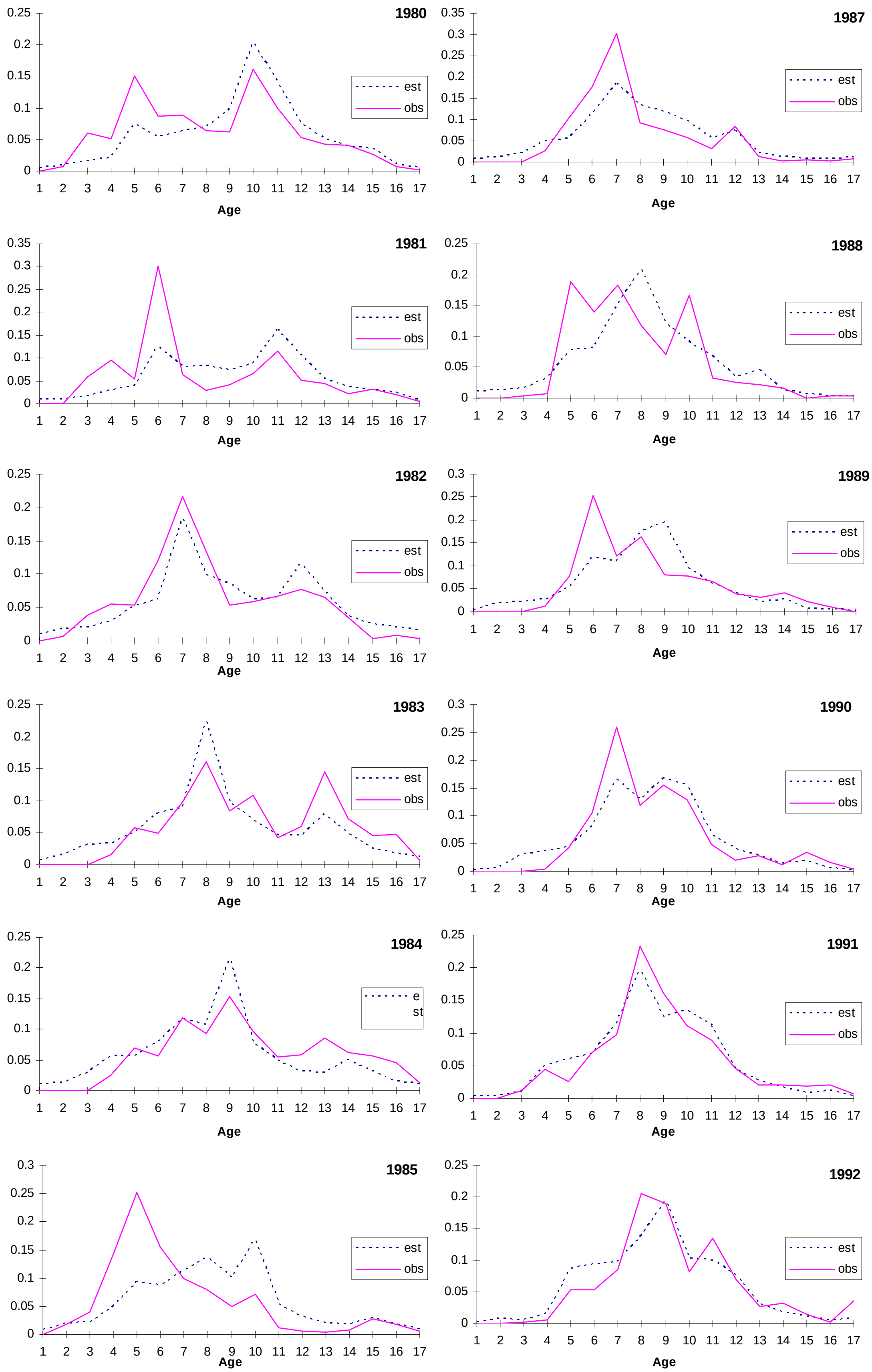
est
obs
Age
0.25
0.2
0.15
0.1
0.05
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
2000
age
0.2
0.15
0.1
0.05
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
2001
age
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1 3 5 7 9 11 13 15 17
2002
age
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1 3 5 7 9 11 13 15 17

(continued)

Fits to the fishery age composition


1980
est
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Age
1987
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Age
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1988
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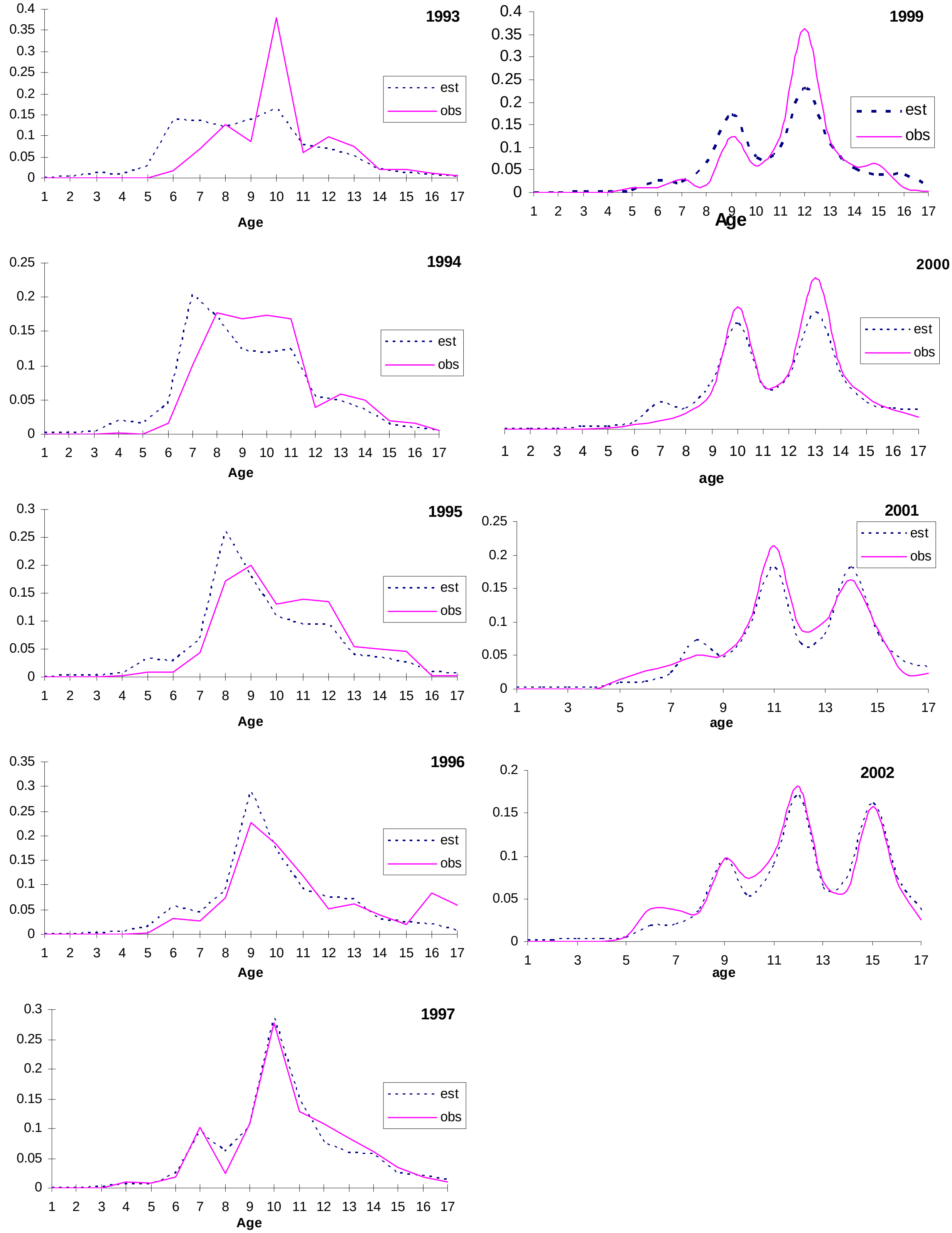
Age

Fits to the fishery age composition (continued)



Model estimates of rock sole population numbers-at-age (thousands of fish), 1975-2003.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1975	323	199	125	127	226	151	82	60	49	45	14	8	5	4	4	4	4	4	4	4
1976	849	270	166	104	105	187	123	65	47	37	33	10	6	3	3	3	3	3	3	6
1977	477	709	225	139	87	87	154	100	52	36	28	24	8	4	3	2	2	2	2	7
1978	721	399	592	188	116	72	72	127	81	41	29	22	19	6	3	2	2	2	2	7
1979	820	602	333	494	157	96	60	60	103	65	33	23	17	15	5	3	2	1	1	7
1980	1,040	685	503	278	412	131	80	49	49	83	52	26	18	14	12	4	2	1	1	7
1981	2,010	869	572	420	232	343	108	65	40	39	66	41	21	14	11	9	3	2	1	6
1982	2,044	1,679	725	477	350	193	284	89	53	32	31	52	32	16	11	8	7	2	1	6
1983	1,796	1,707	1,402	605	398	291	159	231	71	42	25	24	39	24	12	8	6	6	2	5
1984	3,204	1,500	1,425	1,170	504	330	240	130	185	56	32	19	18	30	19	9	6	5	4	5
1985	2,593	2,675	1,251	1,188	971	415	268	188	97	132	38	22	13	12	20	12	6	4	3	6
1986	2,575	2,165	2,234	1,044	989	806	342	218	150	76	102	29	16	10	9	15	9	5	3	7
1987	4,079	2,151	1,808	1,864	870	821	665	278	173	117	58	77	22	12	7	7	11	7	4	8
1988	6,927	3,407	1,796	1,508	1,553	723	679	543	224	137	91	45	60	17	10	6	5	9	5	9
1989	2,500	5,784	2,843	1,497	1,255	1,285	591	543	420	167	100	66	32	43	12	7	4	4	6	10
1990	1,721	2,088	4,829	2,373	1,247	1,042	1,060	481	433	329	129	76	50	24	32	9	5	3	3	13
1991	3,761	1,437	1,743	4,028	1,976	1,035	857	859	381	335	250	97	57	37	18	24	7	4	2	12
1992	1,681	3,141	1,200	1,454	3,357	1,641	854	698	686	298	259	191	74	44	28	14	18	5	3	11
1993	872	1,404	2,622	1,001	1,211	2,786	1,352	694	556	535	229	197	145	56	33	22	11	14	4	10
1994	1,597	728	1,172	2,189	835	1,007	2,304	1,107	559	441	419	178	153	112	43	26	17	8	11	11
1995	766	1,334	608	979	1,825	695	834	1,892	897	447	349	330	140	120	88	34	20	13	6	17
1996	552	640	1,114	508	816	1,520	577	689	1,549	728	360	280	265	112	96	71	27	16	10	19
1997	878	461	534	930	423	679	1,259	474	559	1,239	577	284	220	208	88	75	55	21	13	23
1998	372	734	385	446	776	353	565	1,043	390	457	1,009	468	230	179	168	71	61	45	17	29
1999	485	311	613	322	372	647	293	468	857	318	370	816	378	186	144	136	58	49	36	37
2000	1,089	405	260	511	268	310	537	242	383	695	256	297	653	302	149	115	109	46	39	59
2001	1,418	909	339	217	427	224	258	445	200	314	568	209	242	532	246	121	94	88	38	80
2002	1,051	1,184	759	283	181	356	186	214	366	163	254	459	168	195	428	198	98	76	71	95
2003	1,367	878	989	634	236	151	296	154	175	297	132	205	368	135	157	344	159	78	61	133

Total catch (t) of rock sole in Alaska Fisheries Science Center research catches in the Bering Sea and Aleutian Islands, 1977-2003.

year	research catch (t)
1977	10
1978	14
1979	13
1980	20
1981	12
1982	26
1983	59
1984	63
1985	34
1986	53
1987	52
1988	82
1989	83
1990	88
1991	97
1992	46
1993	75
1994	113
1995	99
1996	72
1997	91
1998	79
1999	72
2000	72
2001	81
2002	69
2003	75